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Training Wayfinding: Natural Movement in Mixed Reality

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14. ABSTRACT *(Maximum 200 words)*:

This report describes an experiment that investigated a prototype mixed reality (MR) system, utilizing the Battlefield Augmented Reality System (BARS), for training wayfinding. BARS is a mobile augmented reality system that uses a head mounted display (HMD) and a wireless system that tracks the users' head position and orientation. In this application a graphic representation of an office space was used as a virtual environment (VE), through which users walked using natural movement. Sixty participants in three rehearsal conditions - drawing the route on a map, actual physical space, and MR – were trained to traverse a path through a complex area as quickly and accurately as possible. Transfer of training measures included route knowledge (time to complete the route and the number of errors committed) and survey knowledge (the ability to orient oneself to the environment and identify the location of the beginning and end of the route). MR participants performed as well as those who rehearsed by drawing the route on a map, in both route and survey knowledge, but not as well as those who rehearsed in the actual space, without reporting symptoms of simulator sickness, common to work in VE. The addition of natural movement to a VE may enhance training through proprioceptive feedback.

15. SUBJECT TERMS

virtual environment, mixed reality, augmented reality, BARS, simulator sickness, mission rehearsal, training

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Training Wayfinding: Natural Movement in Mixed Reality

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TRAINING WAYFINDING: NATURAL MOVEMENT IN MIXED REALITY

EXECUTIVE SUMMARY

Research Requirement:

The U.S. Army needs a distributed training environment that can be accessed whenever and wherever required for training and mission rehearsal. This report describes an exploratory experiment designed to investigate the effectiveness of a prototype of such a system in training a navigation task.

Procedure:

A wearable computer, acoustic tracking system, and see-through head mounted display (HMD) were used to wirelessly track users' head position and orientation while presenting a graphic representation of their virtual surroundings, through which they walked using natural movement. Sixty participants were randomly assigned to one of three conditions: route drawing on a printed floor plan, rehearsal in the actual facility, and rehearsal in a mixed reality (MR) environment. Participants studied verbal directions of route, then performed three rehearsals of the route, with those in the map condition drawing it onto three separate printed floor plans, those in the practice condition walking through the actual facility, and those in the MR condition walking through a three dimensional virtual environment (VE), with landmarks, waypoints and virtual footprints. A scaling factor was used, with each step in the MR environment equal to three steps in the real environment, with the MR environment also broken into "tiles", like pages in an atlas, through which participant progressed, entering each tile in succession until they completed the entire route.

Findings:

A transfer of training test that consisted of a timed traversal of the route through the actual facility showed a significant difference in route knowledge based on the total time to complete the route and the number of errors committed while doing so, with "walkers" performing better than participants in the paper map or MR condition, although the effect was weak. Survey knowledge showed little difference among the three rehearsal conditions. Three standardized tests of spatial abilities did not correlate with route traversal time, or errors, or with 3 of the 4 orientation localization tasks. Within the MR rehearsal condition there was a clear performance improvement over the three rehearsal trials as measured by the time required to complete the route in the MR environment which was accepted as an indication that learning occurred. As measured using the Simulator Sickness Questionnaire, there were no incidents of simulator sickness in the MR environment.

Utilization and Dissemination of Findings:

Rehearsal in the actual facility was the most effective training condition; however, it is often not practical for mission rehearsal. Performance between participants in the other two conditions were indistinguishable, and continued experimentation should include the combined effect of paper map rehearsal with MR, especially as it is likely to be the more realistic case for mission rehearsal. Additional future research should also be conducted to compare the effects of different scaling and tiling factors for different environments and tasks. Future research might also include a direct comparison between this MR, and a VE system through which users move by manipulating an input device such as a mouse or joystick, while physically remaining stationary.

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TRAINING WAYFINDING: NATURAL MOVEMENT IN MIXED REALITY

INTRODUCTION

About thirty years ago, during training in map reading, a U.S. Army basic trainee listened as a drill sergeant instructed the class on map folding and layout, with the caution to keep oneself oriented by always knowing where north was in relationship to the trainee's position. If a trainee found themselves to be so disoriented that they were unable to locate any of the cardinal directions, they were told to "shake a tree, and watch it move on the map". Since the entire class of trainees was very nervous, earnest, and intent on learning map-reading skills, this joke experienced a very flat landing. Now, however, the shake-a-tree method of orientation may have applicability while using training systems with displays of virtual environments (VEs).

The U.S. Army has a continuing need for training, from basic training of new recruits through mission rehearsals, which provides immediate feedback on specific skills, tactics and strategies. The use of simulation technologies provides the opportunity to train in realistic environments without the associated expense of creating physical replications of environments of interest. Mixed reality (MR) technology, in this case providing a three dimensional VE through which the user may walk as if in the actual space, has the potential to provide not only a simulated environment in which to train, but to do so while being mobile. MR has an advantage over an immersive VE in that the Soldier trainee can physically move through the simulated environment using natural movements with less computer equipment than that required to generate a VE.

The system used in this experiment to present the MR was the Battlefield Augmented Reality System (BARS), developed by the Naval Research Laboratory in collaboration with Columbia University. The intended use for BARS is to provide the wearer with information about their surroundings by presenting data from a central command center to the head mounted display (HMD), through which the wearer sees the real world augmented with labels and or graphics. For example, a vehicle driver might have a route laid onto an austere environment where there are few or no landmarks to provide orientation or guidance. Dismounted infantry could be provided information about the location of enemy combatants that has been gathered using unoccupied aerial vehicles, and transmitted to them through a command center. BARS has been demonstrated to be compatible with both indoor tracking systems and global positioning system (GPS) technology, providing an opportunity for outdoor use.

The potential training applications of MR, as presented using BARS or a similar system, are numerous, once the system has been demonstrated to be an effective tool in a specific training task. This experiment is an exploratory study, designed to consider the utility of using MR technology in the training of wayfinding, a basic skill required of all Soldiers, and one that has been used in previous experiments concerned with the effectiveness of training systems.

LITERATURE REVIEW

Among the potential benefits of training for dismounted infantry using VE identified by Nemire (1998) is that it gives users the opportunity to interact with the environment in real time. These multisensory experiences enable the conduct of mission planning and rehearsal exercises on simulated battlefields, providing a level of spatial awareness that is not available with other training media, while minimizing risk to personnel, equipment and the environment.

The use of MR in training should provide the same benefits as VE, while in addition providing the added benefit of the mobility of the technology, its smaller footprint, and reduced programming requirements. Specifically, MR may be useful as a mission rehearsal tool in a theater of operations by providing a tailored rehearsal space created based on information acquired through multiple sources such as unmanned aerial vehicles (UAV) reconnaissance, global positioning systems (GPS), topological maps, city plans, and building plans.

In their discussion concerning the use of augmented reality (AR) in military operations in urban terrain (MOUT), Livingston, Brown, Gabbard, Rosenblum, Yohan, Julier, Swan and Hix (2002) saw BARS as a possible source for embedded training for dismounted warriors. They were interested in how BARS might impact training at three levels: "as a means to blend synthetic and live forces; as a means to provide 'training wheels' to show trainees critical information; and as a tool to assist trainers in constructing and operation a training scenario" (Livingston, et al., 2002, p. 7). Given the typical size and barrenness of a current MOUT facility, BARS was suggested as a tool to add detail to the buildings, as well as to expand the size of the facility virtually, by showing the trainee additional streets and buildings through the BARS HMD. In addition to building features, BARS was considered a potential source for the insertion of synthetic forces, or even live forces from a different MOUT site. The "training wheels" feature of BARS was anticipated to be helpful in identifying critical situations and providing feedback about what had occurred during the training session. Finally, trainers could use BARS to monitor the whereabouts of trainees that were not physically visible, or they could make training scenarios more compelling and difficult.

BARS and the closely related Mobile Augmented Reality System (MARS) have been demonstrated to successfully augment real world scenes, both indoors under a tracking system and outdoors using GPS systems for location data (Columbia University, 2004). Moreover, the computer hardware requirements to produce an AR environment are less demanding than those required to produce a VR environment. The reduced programming requirements for MR, the fact that MR systems can be wearable, and the fact that human can move using natural movement, providing kinesthetic cues not available in maps (Arthur and Hancock, 2001), may make it preferable to VR for training and mission rehearsal.

If MR is as good as or better than traditional training, it is possible that further development efforts for MR as a training tool would be recommended. One step in determining the feasibility of using MR as a mission rehearsal tool is to compare its effectiveness in training navigation skills.

VE has the potential to be as effective for spatial learning as exploration of a real world environment (Arthur and Hancock 2001). While congruency between VE and the real world

may be a concern given scaling issues, the relative relationships of objects and distances between them should accurately transfer from one environment to the other when evaluating transfer of training. Banker (1997) compared three types of navigation training: map study, VE combined with map study, and study in the actual environment, and found that the participants' navigational ability had more of an effect on performance than the training condition. However, within the treatment groups those with intermediate navigational skills benefited the most from exposure to VE. Beginners appeared to be overloaded with information, while experienced navigators used the VE to pinpoint specific locations or waypoints. This study has some minor limitations (e.g., small sample size), but navigation training in VE may still be advantageous over study of a paper map alone in many situations.

The complexity of the environment and path to traverse may make a difference in the effectiveness of VE as a training tool. Schlender, Peters, and Wienhofer (2002) randomly assigned participants to one of five conditions in a desktop VE: having a map available during the entire test, only able to view the map prior to the start of the test, having textual information available throughout the test or only prior to the start of the test, and finally, no additional navigational cues. Overall, having some information available during the test was more effective than having the information available only before the start of the test.

Darken and Sibert (1993) used information about how both birds and humans use real world information, map design, cognitive mapping principles, and how cartographers and planners may use those data, to select tools to facilitate navigating a simple VE. They found they could make some general conclusions about people's predictable use of environmental cues based on the small sample set that they studied. Cues, especially cues that are static and can be seen from anywhere within the environment, are used to divide up a space that is being searched, and to maintain directional relationships. Multi-modal combinations of cues, e.g. auditory and visual, can make targets easier to find. The ability to "fly" over an environment in VE is a tool that allows users the opportunity to store a "bird's eye view" of the environment, which is likely to change how they explore or navigate through that environment. Thus the tool an individual uses makes a difference in their behavior and in task performance. Darken and Sibert (1993) concluded that because their navigational tasks were 2D and performed on a 2D surface, cartographers' design guidelines could be used to extend characteristics of the real world to the virtual world. This led them to suppose that if they had included a 3D task in their study that their 2D maps might have been less helpful.

There are generally three types of knowledge about an environment: landmark knowledge, which is based on information about noticeable objects in an area; route knowledge, which is ego-referenced and acquired by personal travel through an area; and survey knowledge, which is exocentric and acquired through map memorization or exploration of an area using different routes. Using route knowledge allows one to successfully move from one known point to another known point along a specific route using landmarks and waypoints, but it doesn't allow for deviations from the route. Route knowledge allows one to know the approximate distance between landmarks along the route traveled. Route knowledge is formed by sequential travel, which results in better recall when provided in the direction the route was learned, as well as the ability to give directions to guide someone else along the path (Allen & Kirasic, 1985).

Route knowledge does not allow for the creation of short cuts or alternate routes through an environment.

Survey knowledge is typically acquired through multiple explorations of an environment while using different routes, through map learning, or from textual information about the environment. It is characterized by the ability to take an exocentric viewpoint which is then utilized in developing a mental representation of an area as seen from a birds' eye point of view. This mental representation of a physical map is often referred to as a cognitive map (Goldin & Thorndyke, 1982). Survey knowledge built on personal experience gained through exploration of an area is a primary experience (Presson & Hazelrigg, 1984), while survey knowledge that is built through the study of maps or pictures is considered a secondary experience (Goldin & Thorndyke, 1982; Thorndyke & Hayes-Roth, 1982). Some studies indicate that learning survey data from paper maps is inferior to that learned through exploring the area (Presson & Hazelrigg, 1984; Scholl 1993), which is based on the orientation and location of landmarks. Having both route and survey knowledge results in complete navigational knowledge, where the distances between, and location of, landmarks are known and routes can be inferred even though they have not been traveled before.

This experiment compared the effectiveness of paper map based rehearsal, physical route rehearsal, and route rehearsal in an MR environment in achieving an acceptable level of proficiency. This was performed in a manner similar to Witmer et al. (1996), in which training based on rehearsal of the actual route was compared to training based on rehearsal of the route in a VE. Prior to their experiment there had been only a small number of studies conducted that examined training accomplished in VE, with initial work investigating how performance improved with practice but not how the training affected performance in real world settings. Resolution of detail and reduced fields of view were seen as having direct impact on the ability to use VE in training because of the resulting distance discrimination and spatial distortion issues inherent to the display devices available at that time. Locomotion was another factor that Witmer et al. considered, identifying a lack of proprioceptive feedback in VE as a situation that could cause difficulty in estimating distance traveled, as well as lead to symptoms of simulator sickness such as nausea, dizziness or eyestrain.

Perceived personal abilities in navigation (Cevik, 1998; Banker, 1997) and/or spatial orientation were thought to have an effect on participants' motivation and effort in learning the experimental task. Individual differences in feelings of presence or adverse reactions to computer-generated environments, such as motion sickness, were also considered as having a potential impact on participants' acceptance of BARS as a training tool (Bernatovich, 1999; Stanney & Salvendy, 1997). An affinity for computers and other technology used in MR systems may also be a factor if participants engage in computer-based gaming; therefore data was captured on each of these items in addition to participants' objective performance scores.

METHOD

Participants

Participants for this study were 60 volunteers with 20 participants (10 males and 10 females) randomly assigned to each practice condition. The participants were recruited through various on campus communications systems and received compensation in the form of class credit or cash in the amount of $20.00. Most participants were undergraduates, 47% of whom were in their first year of college and ranged in age from 18-52. The average age was 24, while 50% were 18 or 19 years old. All participants reported their visual acuity as 20/20, including those using corrective lenses. None reported visual color deficiency. Only one participant reported being ill within the past week but felt capable of participating as the illness was a common cold that was not impairing any cognitive function.

The number of hours spent each week using a computer ranged from 2 to 60, with a mean of 25 and a standard deviation of 13.36. In addition to time spent using a computer, participants reported an average of 2.89 hours per week spent playing video games, with a range of 0 to 35 hours reported. On a scale of one to ten, one being never misoriented and ten meaning they always have trouble finding their way around, participants on average rated themselves as five, with a range that covered the entire ten-point scale. The largest group of participants indicated they used maps on a monthly basis (27 or 45%), while 9 reported map usage at once a year, and 19 once a week. Five participants reported never using maps. When using a map, 55% (33) reported orienting the map with north always "up" or toward the top of the page.

None of the participants were familiar with the office space used in the study. Each participant completed three spatial abilities tests, a survey of motion sickness history, a survey of simulator sickness history, and a simulator sickness inventory prior to starting the experimental task, and additional simulator sickness inventories at critical points, including the end of their practice sessions. Participants were informed that they were permitted to decline to participate at any point in the study process without penalty.

Equipment and Materials

The route used for this experiment is in a restricted area of the fourth floor of a five story, 75,000 square foot office building in the Central Florida Research Park, Orlando, FL. The route designed for the experiment wound through approximately 7,000 square feet of an area of the building made up of cubicle office spaces. Fifteen survey flags were added as landmarks, 4 each blue, white and pink, and 3 orange. The cubicle area was situated on the south side of the building with a wall of windows on the south side of the space and a dividing walkway on the north side that was located in the approximate center of the building. The north side of the building was made up of hard-walled offices. The route was designed to be confined to the cubicle space except for one segment of the route that entered the walkway. The route included 19 decision points: 12 turns without redundant coding, that is, only one cue given to identify the turn and seven intersections with no direction change.

Clipboards were hung at two specific orientation localization assessment stations along the route. Station 1 was located at the approximate center of the route, and Station 2 was located in the aisle furthest from the starting point. Participants were instructed to stand facing the clipboard, which for station one placed them with their back to the start, while at station two they were positioned with both the start and end points in front of them. At neither position, however, were the participants able to see these points given the intervening office cubicle walls. Please see Appendix B for a diagram of the office space that shows the location of the landmarks and the orientation localization stations. Appendix C is a copy of the diagram that was posted at each orientation localization station.

The diagram in Appendix D is a copy of the floor plan that shows the starting point and the locations of the survey flags that were used for the three practice trials by the paper map condition participants. Participants in the physical route practice condition were moved to the fourth floor cubicle space, within which the experimenter had located the survey flag landmarks. The participants were led to the starting point from which they traversed the route using the directions they had studied.

To create the interactive VE used in the mixed reality condition, a unique combination of hardware, software, and virtual model was used. These components will be detailed in the following sections. Figure 1 provides a depiction of the overall configuration of the MR rehearsal space.

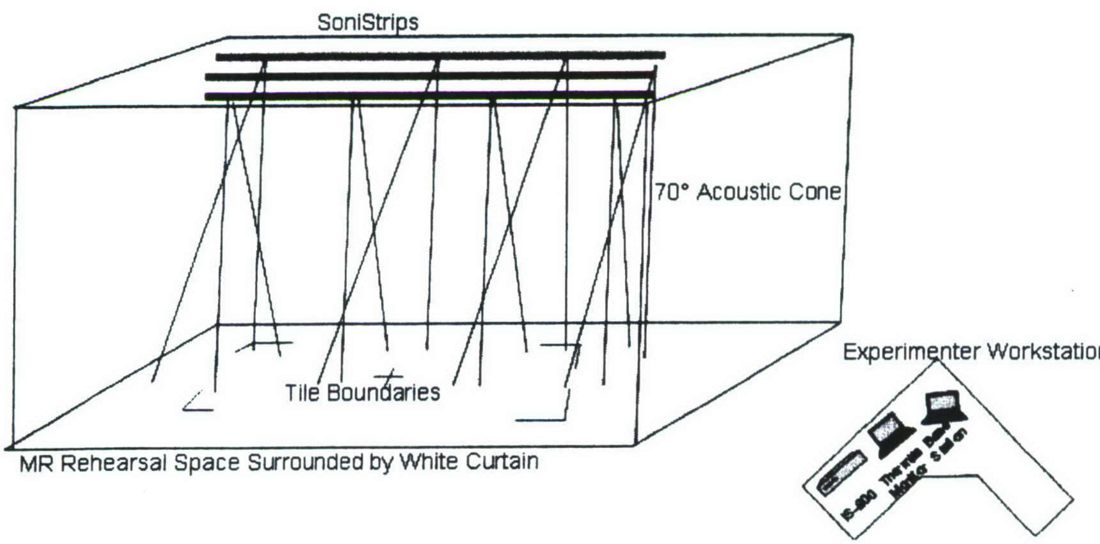

Figure 1. MR rehearsal space and experimenter workstation.

Hardware. The mixed reality condition required a wearable visualization system. The system used was the hardware component of the BARS, created by the Naval Research Laboratory. The BARS system consists of a Quantum 3D Thermite Tactical Visual Computer (TVC) for visual simulation and rendering (Figure 2), paired with a Sony Glasstron HMD (Figure 3). The Thermite computer was equipped with a 1GHz Transmeta Crusoe CPU, an NVIDIA GeForce 5200 GPU, and 480 MB of RAM. While underpowered for the complexity of

the environment, this configuration was sufficient to render and visualize the VE at interactive frame rates of approximately 12 frames per second with latency at 0.02 seconds or less. The Glasstron HMD provides a monoscopic binocular view of the environment at 800x600 pixel resolution. While the Glasstron is capable of providing an optical see-through display, this feature was not used in this work, so the participant saw the virtual image on an opaque screen. A wireless keyboard and mouse provided input control to the Thermite.

Figure 2. Quantum3D Thermite tactical visual computer.

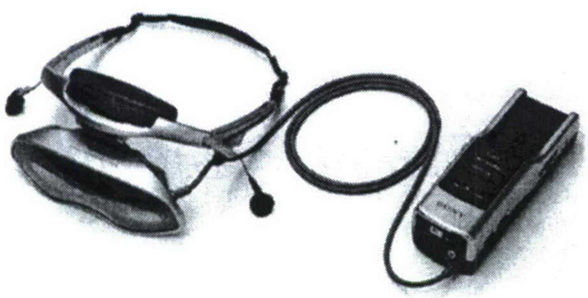

Figure 3. Sony Glasstron HMD.

A Dell Precision 530n workstation was used as a base station. It was equipped with a 1.5 GHz Pentium 4 CPU, an NVIDIA GeForce 4 Ti 4800, and 256 MB of RAM. This computer functioned as a host for the tracking system and provided the experimenter control, a stealth view, of the experimental environment. An InterSense IS-900VET tracking system was used for motion tracking (Figure 4). This system uses a hybrid of inertial and acoustic technologies to calculate a position and orientation for each sensor worn by the user. In this work, the user wore a single wireless motion tracker (Figure 5), mounted on the display visor portion of the HMD, thus tracking the position of the user's head. The signal from the wireless sensor was transmitted to the InterSense base station, and the resulting tracking measurements were then sent back to the wearable computer via an ad-hoc 802.11b connection. A 10x10 foot area was used under the IS-900 sensor strips suspended from the ceiling. The InterSense tracks the participant using six degrees of freedom (X, Y, and Z position plus yaw, pitch and roll orientation).

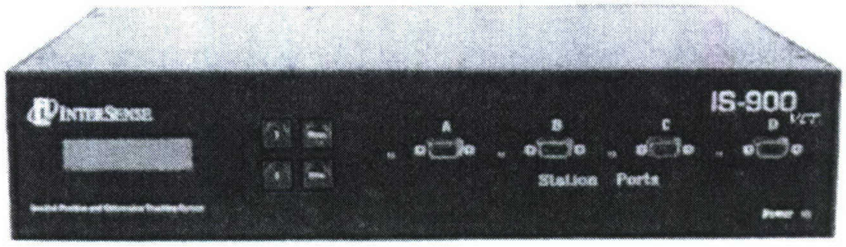

Figure 4. InterSense IS-900 VET base station.

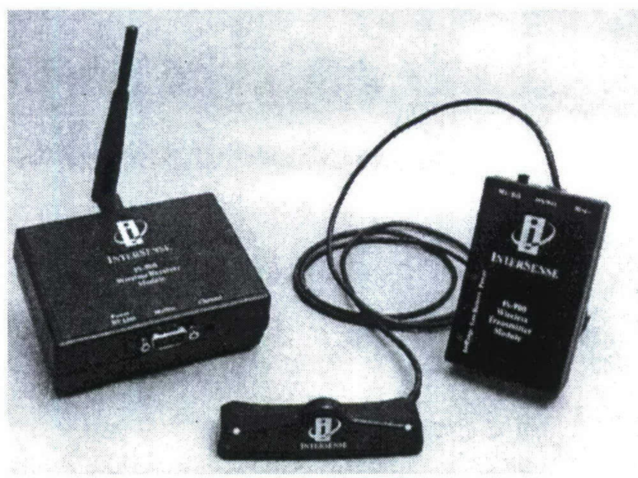

Figure 5. InterSense wireless unit.

Software. Although the BARS system hardware was used, the BARS software was not. The simulation software was based on the Virtual Environment Software Sandbox (VESS) written by the University of Central Florida Institute for Simulation and Training. This particular VESS configuration made use of the Open Scene Graph as an underlying graphics library. VESS adds the capability to drive the InterSense tracking system and convert the tracking measurements into motion in the VE.

In addition to the VE visualization capabilities, the software also included a module that collected the experimental data. The user's position and orientation were captured at 0.1 second intervals and the total route traversal time was also captured. Data was collected directly on the Thermite wearable computer.

The same software in a different configuration was used to drive the experimenter's stealth display. Instead of the first-person viewpoint the user was given, the stealth display showed the environment from above in a top-down view. An avatar was positioned on the display, showing the user's position and orientation, including the use of the previously described footprints. The correct route was drawn as an easy reference for the experimenter.

Due to the Thermite's limited capabilities and the complexity of the VE model, the system was not capable of updating at interactive frame rates. This problem was overcome

through application of a technique known as occlusion culling. The cubicle walls along each row, as well as the walls at the ends of each row, were identified as occluders in the environment. These occluders were compared with the viewpoint at each update cycle. Any geometry that was determined to be behind the occluder surfaces was not drawn. Because of the nature of the environment, occlusion culling significantly reduced the number of triangles drawn during each frame, thus helping to bring the simulation's frame rate up to interactive rates.

Model. The bulk of the virtual model was created using the original Computer Aided Design (CAD) designs for the building as a basis. In addition to providing floor plans for the building and showing where each row of cubicles was positioned, actual 3D cubicle furniture was provided in the CAD drawings. The AutoCAD drawings were converted into the OpenFlight format used by MultiGen Creator. After converting and assembling the various CAD models and creating the remaining building geometry, digital photos were taken of the actual building environment and converted to texture maps. These were then applied to the models.

Several of the CAD furniture models (those with curved surfaces) had a very high triangle count. In an effort to improve the frame rate, these heavyweight models were manually decimated (by selectively removing or combining triangles) without an appreciable loss of detail. After this was done, some of them were further decimated to create a lower level of detail that was used when the user's viewpoint was relatively far from the object.

After the basic environment was complete, it was noted that there were additional pieces of furniture and appliances, such as armchairs, copiers, laser printers, and water fountains, positioned at the ends of the cubicle rows. Since the participants could conceivably use these objects as positional cues, the most noticeable objects were modeled using measurements and digital photos as a reference. When complete, the VE resembled the actual test environment with a high degree of fidelity.

One challenge was to devise a way to allow a 10x10 foot tracking area to provide a realistic walking interface for a VE that was much larger. This challenge was addressed with two techniques. First, the user's real-world motion was scaled up by a factor of three in the VE. This means that one step by the user translated into the equivalent of three steps in the VE. However, the VE was still larger than 30x30 feet. To address this, the software included a tiling system that allowed the user to move about in a single 30x30 foot section of the environment at a time. When the user moved outside the 10x10 foot tracking area, he or she implicitly left the current 30x30 foot tile in the VE. When this happened, the user's display was blanked, and a spotter physically walked the user to the opposite edge of the tracking area. Once repositioned, the display was reactivated, and the user was free to move in the next tile of the VE.

For example, as shown in Figure 6, the route through the first tile might start at the top of the right quadrant and end in the bottom left quadrant.

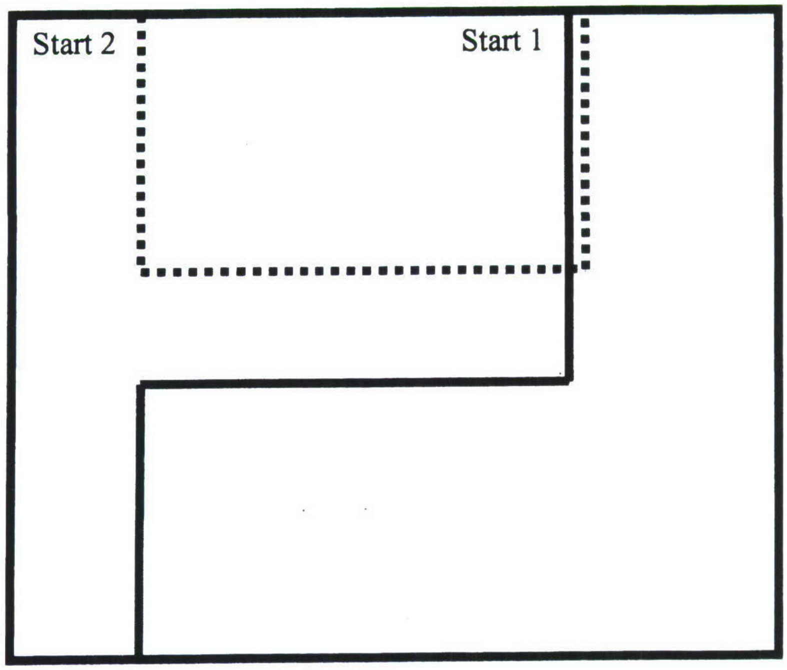

Figure 6. Moving between two sections of the route.

As a visual aid, the user left "footprints" in the VE, showing where he or she had already walked. The footprints were shown as a texture resembling black shoe impressions drawn on the floor wherever he or she had previously been.

Tests of Spatial Abilities

Each participant completed three tests of spatial abilities. The first was the Cube Comparison test from the Manual for Kit of Factor-Referenced Cognitive Tests, (Ekstrom et al., 1976), which is intended to measure the participants' ability to see spatial patterns or maintain their own orientation with relation to objects in space. This test, which was based on L.L. Thurstone's work (Ekstrom et al., 1976) on intelligence testing, required the participant to compare two cubes and determine if they were the same cube in two orientations or two different cubes.

The second test (known as the Surface Development test) was also from the Manual for Kit of Factor-Referenced Cognitive Tests (Ekstrom, et al., 1976) and was intended to measure the participants' ability to mentally manipulate or transform a diagram into another arrangement. For this test participants were presented with a drawing of a solid object that could be created by folding paper, while next to it was a drawing of an unfolded piece of paper, which might be folded to create the solid object. The unfolded diagram had one marking that corresponded to a mark on the solid object and several edges of the diagram were numbered. The task was to show which of those numbered edges corresponded to the lettered edges of the solid object.

The third spatial abilities test was the spatial orientation test from the Guilford-Zimmerman Aptitude Survey (Guilford, 1948), which was based on work done with aircrew members during World War II. The intent of this test is to measure participants' awareness of

spatial relationships, emphasizing direction of movement by using pictures of boats and relationships with the surrounding environment and the visible horizon. Two pictures are presented, the second of which shows the result of some change of position, which the participant is to describe by choosing among the five options presented.

Questionnaires

Participants completed three questionnaires. The first captured demographic information. The second, the Motion History Questionnaire (MHQ; RSKA Form MHQ-1, Rev. 5/01; Kennedy et al., 2001), captured participants' past experience with motion sickness. It asked them to compare themselves to others by estimating the likelihood of them becoming motion sick in situations where various percentages of other people might get motion sick, and asked if they would volunteer for an experiment where various percentages of other people did get motion sick. A matrix presented on a separate page listed 14 situations in which one would experience motion, from aircraft through motorcycles. The participants were asked to list their preference for these situations (Like, Neutral or Dislike), and to mark any symptoms they had experienced in any of these situations. This was scored as described by Kennedy, et al. with each scale that was anchored with a "never" condition scored as 0 points and "always" or "extremely" scored as 4. Questions with "yes" or "no" answers were scored 1 or 0 respectively. The situations from question 15 that were used in the data analyses were scored as 1 if marked by the participants and 0 if not marked, and limited to the following, as described by Kennedy et al. (2001). See Table 1.

Table 1. Situational Data Taken from Question 15 of MHQ

Situation	Like	Neutral	Dislike	Vomited	Nausea	No Symptoms
Aircraft	1/0	1/0	1/0	1/0	1/0	1/0
Flight Simulator	1/0	1/0	1/0	1/0	1/0	1/0
Roller Coaster	1/0	1/0	1/0	1/0	1/0	1/0
Other Carnival Device	1/0	1/0	1/0	1/0	1/0	1/0
Long train or bus trip	N/A	N/A	N/A	N/A	N/A	1/0
TOTAL	0-4	0-4	0-4	0-4	0-4	0-5

The Simulator Sickness Questionnaire (SSQ), also developed by Kennedy (Kennedy et al., 1992), was used as a screening tool to be certain that participants were not experiencing any symptoms of illness that might cause them to experience simulator sickness while in the MR environment, and as a monitoring tool throughout the rehearsal and transfer of training testing. The SSQ is a checklist of 16 symptoms, which are scored on the basis of the participants' experience of the degree of severity of each symptom (none, slight, moderate, severe, scored as 0, 1, 2, and 3, respectively). A weighted scoring procedure is used to obtain the global score intended to reflect the overall discomfort, or Total Severity (TS), in addition to three subscales representing separable dimensions of simulator sickness (i.e., nausea, oculomotor disturbances, and disorientation). Score values were calculated using both the original unit weighting procedure as described by Kennedy et al. (1992), and an un-weighted procedure used by Knerr et al. (1998). The SSQ was administered to participants upon arrival, after each MR training session, and prior to departure from the experimental area.

Experimental Design

Research Questions. The consideration of a MR environment as a training system generated a series of research questions, some of which have to do with the effectiveness of such a training tool as measured through transfer of training testing, while others are concerned with the experience of the individuals interacting with the MR including the possible occurrence of simulator sickness. The major questions were as follows:

1. How does the effectiveness of rehearsing a wayfinding task using MR compare with that of drawing a route on a floor plan (a paper map) or rehearsal in the actual test environment in terms of route and or survey knowledge?

2. Are spatial abilities test scores (Cube Comparison, and Surface Development from the Manual for Kit of Factor-Referenced Cognitive Tests, (Ekstrom et al., 1976), and the Guilford-Zimmerman Aptitude Survey test of spatial orientation (Guilford, 1948)) correlated with participants' performance on the three performance measurement tasks of time to traverse the learned route, number of errors committed in the timed trial of route traversal, and the ability to be oriented enough to locate the position of the beginning and ending of the route from two separate locations along the route?

3. Is rehearsal of route traversal in the mixed reality environment successful as a training tool as evidenced by the improved performance, measured by decreased total time for each successive trial in the mixed reality environment?

4. Will participation in route rehearsal in the MR environment cause greater symptomology of simulator sickness than in the non-MR environments?

Task and Procedure. The experimental task was to train participants through the use of three different rehearsal conditions to traverse a specific path through a complex area as quickly and accurately as possible, while also demonstrating an exocentric, or survey knowledge of the surrounding environment. A direct comparison between the three rehearsal conditions (drawing the studied route on a floor plan, walking through the physical route as rehearsal and MR rehearsal) was undertaken by capturing participants' route traversal time, and by counting errors in route traversal, (i.e., wrong turns). In addition, error data was collected concerning participants' localization orientation; that is their ability to identify the location of the start and end of the route in reference to their current position.

Participants in each condition were greeted and randomly assigned to one of the three rehearsal conditions. Detailed procedures and instructions to participants are included in Appendix E. Each of the 60 participants was assigned a participant number for use in tracking data while maintaining participants' anonymity. After reading and completing an informed consent form, each participant was asked to complete each of the following items in turn: Demographics Questionnaire, MHQ, and SSQ with Baseline Exposure Symptom Checklist. Demographic information that was gathered included gender, age, own belief of spatial orientation and time spent using computers and maps. A sample of this questionnaire can be found in Appendix F. Each participant then completed three tests of spatial abilities, as follows:

Cube Comparison, Surface Development, and the Guilford-Zimmerman Spatial Orientation subtest. Upon completion of all of the above each participant was presented with a short description of the experiment that varied according to which of the three rehearsal conditions they had been assigned. Once the participant indicated that they understood the rest of the experiment and that they were willing to proceed, they were presented with written directions that described the route they were to learn. Each participant was allotted 15 minutes to study these directions, after which the directions were removed. Participants were not permitted any aids for memorization and were not to write out the directions or draw what they believed the route to be.

Paper Map Condition: Participants in the paper map practice condition rehearsed the route by drawing the route they had learned through memorizing the directions on a printed floor plan of the office space environment that showed walkways, landmarks and waypoints. The participants were allotted three practice trials under the supervision of the experimenter who identified errors as they were committed by saying "Stop". Errors were identified as soon as it was clear that the participant was committed to a particular movement. For example, if the participant turned right at an intersection instead of left, the experimenter would wait until the participant had started to draw the line that would connect them to what they thought the next landmark was before stopping the participant. The participant returned their pencil to the last known correct point and attempted a different strategy, without being told what the next move should be by the experimenter. This procedure was repeated as necessary to move the participant through the rehearsal phase, after which the participant was moved to the actual office space, to perform a single timed and scored traversal of the actual physical route.

Walking condition: Participants in this rehearsal condition, known as "walkers," executed three practice traversals of the route in the actual facility. During this rehearsal phase any errors committed by the participant were identified to the participant by the experimenter saying, "Stop," after it was clear that the participant was committed to a particular erroneous movement. For example, if the participant turned right at an intersection instead of left, the experimenter would wait until the participant had taken two steps in the wrong direction before stopping them. At that point the participant was moved back to their last correct position and instructed to proceed from there, repeating this procedure as necessary to move the participant through the three practice traversals of the route. After the third rehearsal of the route with corrections, the participant performed a single timed and scored traversal of the route.

MR condition: Participants in the MR condition also executed three practice traversals of the identified route as it was presented in the third floor laboratory space. The Sony Glasstron provided the participant a three dimensional recreation of the office space showing cubicle walls, office furniture, landmarks, waypoints and virtual footprints. Virtual footprints are a "you were there" display that leaves a visible trail of footprints that the participant can see through the display showing their own movement to assist in orientation. (Grammenos, Filou, Papadakos, and Stephanidis, 2002).

Participants' location in the training area was tracked using IS-900 tracking system, to provide data to the Thermite computer, which presented the appropriate display to the participant while also providing data to the Dell computer which provided a display for the experimenter to

monitor the participants' movement. The stealth view is the floor plan shown on a 17-inch computer monitor with the tiles indicated with black lines and the route shown with a white line. An avatar in the stealth view shows the participant's location and the virtual footprints show where they have walked.

To familiarize participants with the MR environment, a familiarization session was conducted prior to their memorization period so as to avoid any MR environment specific learning impact on participants' rehearsal time. Two tiles that had been modeled but were beyond the periphery of the tiles through which the test route passed were used in this familiarization session. Each participant donned and was fitted with the BARS ensemble, then led to a starting point in the training area that did not correspond to the starting point of the test route. While standing on the edge of the space that defined each tile, the participant was oriented to the boundaries of the tiles by identifying the four corners of the tile shown with blue tape on the beige colored carpet. They were instructed on the specifics of the scaling factor, that each step they took in the rehearsal space was worth three steps in the actual space and that the actual space would be represented by six tiles that worked like pages in an atlas. It was pointed out that while it was possible to walk through walls and furniture in this environment, there was no advantage to doing so. Finally they were told that to successfully complete the route they were about to learn, they would have to walk outside the bounds of the tile, past the blue lines, and within three seconds of doing so, the Glasstron display would turn black. They were to stop moving until instructed as to where they should move to pick up the continuation of the route. For this familiarization however, they were free to roam through the space to become familiar with the look and feel of the environment. When they indicated that they understood the concept and felt familiar with it, a process accomplished in a span of 15 minutes on average, the MR participant was removed from the rehearsal area, completed a simulator sickness inventory, and doffed the BARS ensemble, after which they were given 15 minutes to study the route as in the other two conditions.

At the end of the 15 minute study period the participant donned the BARS ensemble and moved into the rehearsal space with the spotter. After each rehearsal trial, the participant was asked to complete a simulator sickness inventory, and after the third rehearsal also doffed the BARS ensemble and moved to the actual office space where they performed a single scored traversal of the route.

The MHQ and the SSQ were used to evaluate participants' possible susceptibility to sickness in VEs, as well as to monitor symptoms that might appear during MR exposure. Participants' responses to the SSQ Exposure Checklist were captured at various times throughout the course of the experiment, dependent upon the assigned experimental condition. Those participants who drew the route on a floor plan for rehearsal and those who walked through the actual office space each completed the checklist at the end of their rehearsal period, before performing the transfer of training tests of route traversal and orientation localization. MR condition participants completed the checklist after the familiarization exposure to the MR environment, after each of the three rehearsal trials in the environment, and after performing the transfer of training tests, which was typically 10 minutes after their exposure to the MR environment.

The effectiveness of the training was assessed using data gathered during the traversal of the actual route without using the paper map, correction from the experimenter or the BARS ensemble. Participants were instructed that speed and accuracy in traversal of the path were of equal importance. At two points along the route, from which participants could not see either the beginning or end of the route, the participants were stopped in front of a clipboard hanging from a cubicle wall, on which was posted an 8.5" x 11" piece of paper showing a circle with an X in the center and the numbers 12, 3, 6, and 9 around the edge for orientation points (See Appendix C). They were asked to imagine themselves standing on the X facing the 12 and to mark where they believed the starting point of the route was in relation to where they were standing, by writing an S on the circle, and to mark where they believed the end of the route was by writing an E on the circle.

Four performance variable data sets were gathered, with the first two variable sets used to measure route knowledge, which included total time to traverse the route, and number of traversal errors (wrong turns). The second two variable sets, used to measure survey knowledge, included data from the participants' input on each of the orientation localization tasks located at two reporting stations along the route. This survey knowledge was based on the absolute error between the actual location of the start and end points of the route from each of the two reporting stations, and the participants' input as to where they believed the start and end points of the route to be located. The location of the two orientation localization stations and the start and end points of the route are illustrated in Appendix B.

RESULTS

This section describes the data analysis for the experiment. The first section outlines the experimental variables, self-report measures, and demographics collected. The second section presents the data for the three experimental conditions on the performance measures examined.

Description of Variables and Measures

Prior to analysis, descriptive statistics were examined for each experimental variable, and all variables were screened for normality, outliers and missing values, and appropriate transformations applied. Each of the performance variables, that is Number of traversal errors, Total time to complete route, and the variables that captured the value in degrees of error from each orientation localization station (Error to Start Station 1, Error to End Station 1, Error to Start Station 2 and Error to End Station 2) were transformed by using the mean to replace any missing data and the top five univariate outliers. SPSS version 11.5 was used, with alpha set to .05 unless otherwise specified.

Effectiveness of MR on Performance Measures

Route knowledge. A between subjects analysis of variance was conducted, in which the independent variable was rehearsal condition (paper map, walker, mixed reality). As can be seen in Table 3, the analysis of variance was significant for Total Number of Errors in Route Traversal, with $F\,(2, 57) = 6.24, p < .001$, with a partial η^2 of 0.18. Participants in the walker condition averaged 0.85 errors, the MR participants 3.47 errors, and the paper map participants committed an average of 4.39 errors. Post hoc tests using a Scheffe adjustment for multiple comparisons, shows that participants in the walker condition, that is those that rehearsed the route in the actual office space, consistently performed better than those in either the paper or mixed reality conditions.

Table 2. Analysis of Variance for Traversal Errors

Source	*df*	*F*	η^2	*p*
Total Traversal Errors	2	6.24	.18	.000
Error	57			

Table 3. Post Hoc with Scheffe adjustment for Traversal Errors

Condition	Condition	Mean Difference	*p*
Walker	Paper Map	-3.545	.005
	Mixed Reality	-2.6186	.050
Mixed Reality	Paper Map	-.9271	.675

A between subjects ANOVA was conducted using the rehearsal conditions and the dependent variable Total Time to Complete the Route. The Total Time was significant at $F\,(2, 57) = 9.42, p < .001$, and a partial η^2 of .25. Participants in the walker condition averaged 1.99 minutes to complete the route, MR participants averaged 3.25 minutes, and paper map participants 3.77 minutes.

Table 4. Analysis of Variance for Time to Complete Route

Source	*df*	*F*	η^2	*p*
Total Time to Complete	2	9.416	.18	.000
Error	57			

Post hoc tests using a Scheffe adjustment for multiple comparisons shows that participants in the walker condition, that is those that rehearsed the route in the actual office space, consistently performed better than those in either the paper or mixed reality conditions.

Table 5. Post Hoc with Scheffe adjustment for Time to Complete

Condition	Condition	Mean Difference	*p*
Walker	Paper Map	-1.786	.000
	Mixed Reality	-1.264	.004
Paper Map	Mixed Reality	.523	.222

Survey knowledge. A between subjects analysis of variance of the pointing error data was conducted using rehearsal condition (paper map, walker, mixed reality) as the independent variable. The data analyzed were the error in degrees made in pointing from each of the location stations to the start and end positions of the route. The analysis of variance was not significant for the any of these measures.

Comparison of Spatial Abilities Tests to Performance Measures

To examine the relationship between tests of spatial abilities and route knowledge test performance measures, a correlational analysis was conducted using SPSS. Specifically the variables were: Cube Comparison Test, Surface Folding Test, Guilford-Zimmerman Spatial Orientation Test, Total Time to Complete Route, and the Number of Traversal Errors with adjustment for outliers as described above. Table 8 shows the descriptive statistics that describe the performance of participants on the spatial abilities tests, while Table 9 displays the correlations among the variables.

Table 6. Descriptive Statistics of Spatial Abilities Tests

Test	Mean	Standard Error M	Median
Cube Comparison	17.78	1.45	18.5
Surface Development	36.15	1.89	35.5
Guilford-Zimmerman	11.81	1.19	11.25
Cube Comparison	17.78	1.45	18.5
Surface Development	36.15	1.89	35.5

The specific hypothesis that the three tests of spatial abilities would be related is only supported for the relationship between Surface Development and Cube Comparison, $r = 0.381$, $p < 0.01$, and between Surface Development and the Guilford-Zimmerman task where the r =

0.451, $p < 0.01$. A relationship between the Cube Comparison and the Guilford-Zimmerman tests was not established in this study.

Route knowledge. Neither of the performance variables correlated with the tests of spatial abilities. However, the Total Number of Errors made during route traversal was positively correlated with the time to complete the route, $r = 0.639$, significant at the 0.01 level. Logically, this indicates that as the number of errors increased, so did the amount of time required to complete the route.

Table 7. Correlation of Spatial Abilities Tests and Route Knowledge

Variables	Cube	Surface	G-Z	Time	Errors
Cube Comparison	1.00				
Surface Development	0.381**	1.00			
Guilford-Zimmerman	0.214	0.451**	1.00		
Total Time to Complete	-0.105	-0.031	-0.174	1.00	
Traversal Error	0.044	-0.201	-0.146	0.639**	1.00

**Correlation is significant at the 0.01 level (2 tailed)

Survey knowledge: To examine the relationship between the tests of spatial abilities and survey knowledge performance measures, a separate correlation analysis was conducted using SPSS. Specifically the variables were: Cube Comparison Test, Surface Folding Test, Guilford-Zimmerman Spatial Orientation Test, Error Start 1, Error End 1, Error Start 2 with outliers and missing data transformed as described above. Table 10 displays the correlations between the variables, where the correlations among the three spatial abilities tests are again apparent. The Cube Comparison test is negatively correlated with the Error to End from Station 2, ($r=-.249$, $p<.05$), while the Guilford-Zimmerman Test is negatively correlated with the Error to Start from Station 2, ($r=-.260$, $p<.05$). The Surface Development Test is negatively correlated with Error to Start from Station 1 ($r=-.275$, $p <.05$) and Error to End from Station 1 ($r=-.294$, $p< 0.05$), and Error to Start from Station 2 ($r= -.364$, $p<.0.01$). The Error to the End of the Route from Station 1 is positively related to the Error value for identifying the location of the End of the Route from Station 2 ($r= .255$, $p< 0.05$).

Table 8. Correlation between Spatial Abilities and Survey Knowledge Performance

Variables	Cube	Surface	G-Z	Start 1	End 1	Start 2	End 2
Cube Comparison	1.00						
Surface Development	.381**	1.00					
Guilford-Zimmerman	.214	.451**	1.00				
Error Start Station 1	-.054	-.275*	-.208	1.00			
Error End Station 1	-.194	-.294*	-.181	.437**	1.00		
Error Start Station 2	-.248	-.364**	-.260*	.077	.195	1.00	
Error End Station 2	-.259*	-.165	-.081	-.061	.255*	.122	1.00

* correlation is significant at the 0.05 level (2 tailed)

**correlation is significant at the 0.01 level (2 tailed)

It would appear that as scores on the Surface Development test increase, so do the scores on the Cube Comparison and Guilford-Zimmerman tests, so that higher scores on Surface Development, which indicates greater ability in this type of spatial task, is related to greater

ability in comparison of cubes and in spatial orientation as measured by the Guilford-Zimmerman test. As these scores on standardized tests of Spatial Abilities increase, participants' localization scores decrease significantly. As the ability in spatial tasks improves, so does the ability to localize the beginning and end of the route. Since these values are difference error values between the actual location of the point of interest and the location the participant expected the point to be, the lower score is more desirable. As the amount of Error to the End of the Route from Station 1 increases, so does the amount of Error to the End of the Route from station 2 increase, showing some consistency in the participants' perceptions of the route and the layout of the environment through which it passed.

Learning in Mixed Reality

As has been described previously, the model of the office space was broken into tiles, and the tiles were explained to participants as being similar to the pages of an atlas so that when they ended a route segment at the edge of one tile they would start the route again from that same point at the edge of the next tile. While the participants were never shown a drawing of the environment or the tiles, the experimenter, to monitor the participants' current position and progress through the environment, used the diagram of the environment presented on the second computer. With a sampling rate of approximately once per second, data was captured that was saved to a file with a time stamp, an X coordinate, which was the participant's head pitch, a Y coordinate, which was the head roll, and a Z coordinate, that was the head yaw, and the tile coordinate number. That position data was also used to generate an avatar, which showed the experimenter where the participant was in the environment. The graphic below shows the environment with black lines that indicate the boundaries of the tiles, a white line that describes the route, and the coordinate names for each of the tiles.

To determine whether learning occurred over the three rehearsal trials, an analysis of variance was performed using SPSS, with an alpha level of .05. Because of an unequal number of participants in gender, which occurred when the data for the first male subject was inadvertently over-written on the Thermite computer, the data for the first female participant was removed from further analysis, chosen on the basis of matching the first male participant. The grouping variable was rehearsal trial (1, 2 and 3) and all variables were screened for normality, outliers and missing values. There were 18 participants (nine female and nine male), each of which performed three rehearsal trials. As can be seen in Table 11, the analysis of variance showed a significant effect of rehearsal trial on the total time spent on each tile, except Tile 1,1.

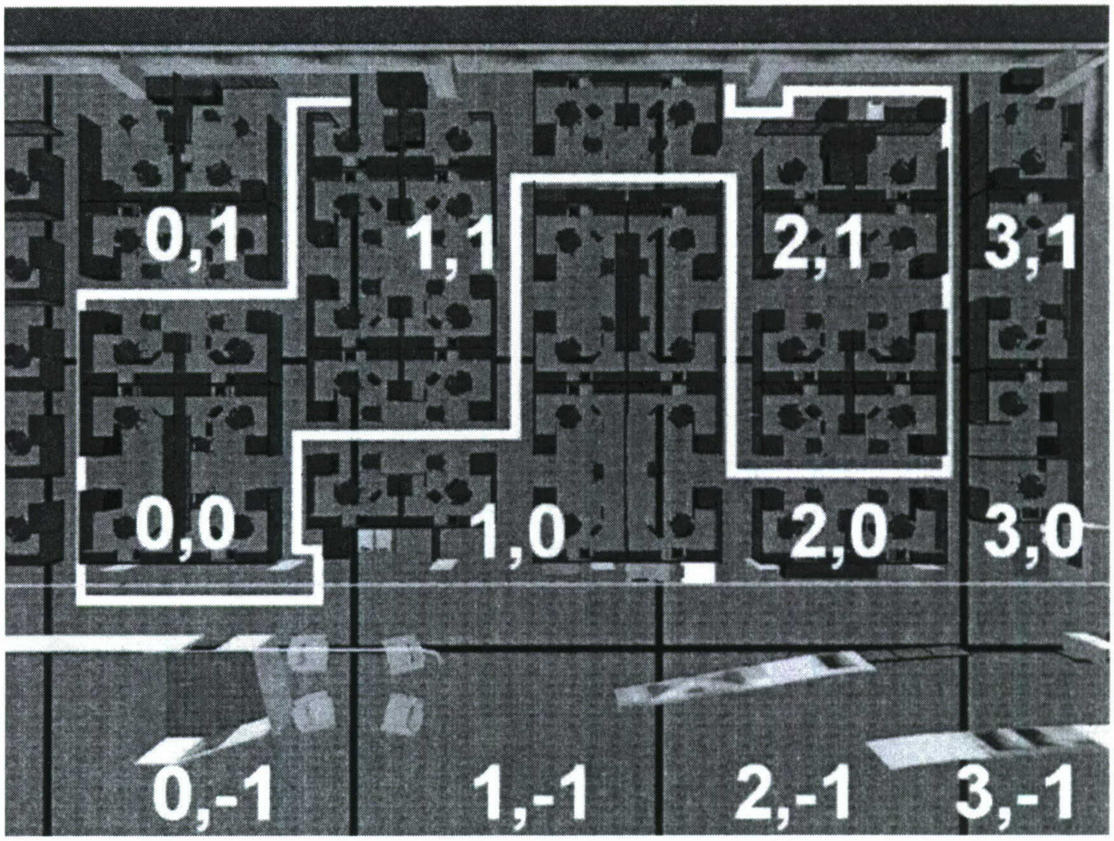

Figure 7. Model diagram showing tiles, tile coordinates and route

Table 9. ANOVA for Time spent in each Tile over 3 Trials

Source	df	*F*	*p*
Tile 0,1	2	9.161**	.000
Error	51		
Tile 0,0	2	23.64**	.000
Error	51		
Tile 1,0	2	3.58*	.035
Error	51		
Tile 1,1	2	.893	.416
Error	51		
Tile 2,1	2	5.970**	.005
Error	51		
Tile 2,0	2	7.187**	.000
Error	51		

* $p<.05$
** $p<.01$

Post hoc comparisons, with a Scheffe adjustment, compared the three trials to find if there was a significant difference between the first, second and third trials in each tile. While the difference between adjacent trials for each tile were not always significant, there was overall

significant improvement on five of the six tiles. Tiles 0,1 and 0,0 showed significant improvement between Trials 1 and 2, 2 and 3, and 1 and 3. Tiles 1,0, 2,1, and 2,0 showed significant improvement between Trials 1 and 3. There were no significant differences among the three trials in Tile 1,1. Times are shown in Table 11.

Table 10. Means of Three Rehearsal Trial Times by Tile

Trial No.	1		2		3		Total	
Tile	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
Tile 0,1	101.13	68.48	58.03	37.96	36.71	14.75	65.29	52.61
Tile 0,0	170.37	94.09	65.34	32.19	46.84	15.77	94.18	79.16
Tile 1, 0	37.00	17.39	29.12	10.81	26.57	5.10	30.90	12.76
Tile 1, 1	39.96	20.19	36.87	22.37	31.32	15.85	36.05	19.62
Tile 2, 1	158.44	117.05	94.92	66.01	66.91	42.84	106.75	88.74
Tile 2, 0	61.19	32.08	45.71	13.8	34.43	11.66	47.11	23.61

MR and Simulator Sickness

An analysis was conducted of participants' past experience with motion and motion sickness, as well as their perception of the likelihood of experiencing motion sickness and the occurrence of simulator sickness symptoms during or after exposure to the MR. There was no difference among the participants of the three rehearsal conditions with respect to the prediction or expectation of motion sickness, and therefore simulator sickness while in the MR rehearsal condition (F (20, 86) = .641, p> .05, partial η^2 = .13).

Participants' perceptions of their own susceptibility to motion sickness were then compared to weighted and un-weighted simulator sickness scores calculated from participants' responses to the simulator sickness inventories completed throughout their experimental trial. A multivariate analysis of variance was conducted using SPSS version 11.5, with an alpha level of .05 unless otherwise stated. With the use of Wilks' criterion, the combined dependent variables (DVs) were not significantly effected by participants' beliefs concerning their susceptibility of motion sickness, with F (16, 100) = .559, p> .05, and a partial η^2 of .08. This lack of significance was taken as an indication that there was no connection between participants' expectations about motion sickness and actual ratings of simulator sickness throughout the three conditions of the experiment.

The tendency for participants to experience symptoms of simulator sickness with exposure to the MR was examined through analysis of variance using SPSS version 11.5, and an alpha level of .05. All participants had completed pre and post test SSQ inventories. This procedure resulted in a maximum of two reports from the walkers and the paper map rehearsal participants, and a maximum of six from the MR participants. Therefore, for this analysis to examine simulator sickness while comparing MR to the non-MR conditions, only the single post test inventory from the walkers and paper map participants were used, while the post third rehearsal inventories from the MR participants were used. Given the cumulative properties of

simulator sickness, this was considered to be the worse case for the MR participants. There were no outliers, and the results of the evaluation of assumptions of normality were satisfactory.

Table 11. ANOVA Post Test SSQ (W) Inventory

Source	df	F	p
SSQ TS W	2	.136	.873
Error	57		
SSQ N W	2	.019	.982
Error	57		
SSQ O W	2	.626	.538
Error	57		
SSQ D W	2	1.702	.191
Error	57		

Table 12. ANOVA Post Test SSQ (R) Inventory

Source	df	F	p
SSQ TS R	2	.128	.880
Error	57		
SSQ N R	2	.019	.982
Error	57		
SSQ O R	2	.626	.538
Error	57		
SSQ D R	2	1.702	.191
Error	57		

With the use of weighted SSQ values, there was no difference among the three rehearsal conditions. Total Severity of sickness was not significant with $F(2, 57) = .136, p > .05$, nor was Nausea with $F(2, 57) = .019, p > .05$, or Oculomotor with $F(2, 57) = .626, p > .05$, or Disorientation with $F(2, 57) = 1.702$, p> .05.

A separate analysis was conducted using the un-weighted SSQ values, and there were no differences among the three rehearsal conditions in symptomology. Total Severity of sickness was not significant with $F(2, 57) = .128, p > .05$, nor was Nausea with $F(2, 57) = .019, p > .05$, or Oculomotor with $F(2, 57) =.626, p > .05$, or Disorientation with $F(2, 57) = .191$, p> .05. The results of these analyses would indicate that rehearsal conducted in this type of MR does not produce significant symptoms of simulator sickness.

DISCUSSION

This research was exploratory in nature, to determine if training in an MR environment, as provided by the BARS, was effective. If so, BARS or similar technologies could be a solution for multiple training situations with needs that are met either partially, or not at all, by current technologies. An effective mission rehearsal tool for dismounted infantry to use as they learn their way through an unknown environment has the potential to enhance Soldiers' capabilities and improve survivability rates. Given current technology in information acquisition in the form of cartography, and imagery from multiple sources, there are multiple methods for gathering the data to input to this potential mission rehearsal tool, as well as the software and hardware to construct it.

This experiment has addressed the following questions:

1. How does the effectiveness of rehearsing a wayfinding task using MR compare with that of drawing a route on a floor plan (a paper map), or rehearsal in the actual test environment in terms of route and or survey knowledge?

Rehearsal of the wayfinding task in the actual office space was the most effective in decreasing the time and errors of the participants on the transfer task. This result should not be surprising, but it is also an option that is usually not available for mission rehearsal, given a remote and or hostile environment, where the area may be under threat. Participants who rehearsed the route by drawing it on a floor plan performed at a level that was indistinguishable from those who rehearsed in the MR environment. It was expected that the kinesthetic learning inherent to walking through the route, whether in the actual space or in the MR, would improve performance. This was not supported in the MR condition. The experimental conditions that were not addressed include map study, and the combined effect of map study and MR, which is likely to be the more realistic case for mission rehearsal. Soldiers will likely have maps available, but to have walked through the environment beforehand can only enhance the Soldiers' understanding of their surroundings. The repeated comments gathered from participants in the MR condition such as "This looks like I was just here" and "There's that pole I kept having trouble with," suggest that this is a tool to continue to explore and apply.

The minimal difference among the survey knowledge measurements shows that MR was as good as walking through the actual facility or drawing the route on a map. The mean difference between MR and walking in locating the end of the route from the orientation localization station number one was about 29 degrees. This type of knowledge might have been enhanced in either of these conditions if participants had been given the opportunity to divert from the learned route to develop a better cognitive map of their surroundings, creating short cuts that might later turn to escape routes. With the addition of a map of the environment Soldiers would likely learn the ins and outs of an environment thoroughly before arriving at the actual location.

The lack of a significant difference between the map and MR groups and the superiority of the walker condition to both in terms of transfer task performance is not inconsistent with previous research. Darken, Allard, and Achille (1999), in discussing VR research results in the

area of wayfinding, observed that VEs have been shown to be effective for acquiring spatial knowledge, a conclusion confirmed using MR in this experiment. They further noted that mixed results had been obtained when comparing VE with the real world. They attributed these inconsistencies to differences in the VE systems, environments, and training methods used. Likewise, as reviewed by Koh, Wiegand, Garnett, Durlach, and Shinn-Cunningham (1999), comparisons of map and VE training have produced mixed results in terms of real-world performance, with map training better in some experiments, and VE training better than others.

Two factors may have reduced the potential differences between the map and MR groups in this experiment. First, consider that MR has the capability to present visual representations of landmarks from the perspective of the trainee, while a map does not. In the initial training session, prior to MR or map practice, all groups studied the route they were to take using a combination of textual directions and photographs of the route from their perspective. While the MR trainees received more exposure to the visuals of the route than did the map trainees, all trainees received some exposure to them, and this may have improved the performance of the map group. Second, the change of scale and tiling used in the MR condition to meet physical space constraints may have confounded and reduced the effectiveness of the kinesthetic and proprioceptive cues the trainees would otherwise have received. The use of these scaling and tiling techniques requires further research. It would be premature to conclude that training with maps is equivalent to training with MR or VE.

It is possible that some dominant visual characteristics of the space helped prevent participants from making large errors when indicating the start or end point. The start and end point were both located along a window wall, with corridors running at right angles either perpendicular to or parallel to that wall. As long as a participant recognized those features and thought about what they were doing, it was hard to make a very large error when indicating the start or end point. It may be that there was a ceiling effect limiting error which precluded finding any significant differences.

Walking through the real environment provides vestibular and kinesthetic cues about direction and distance. In the MR environment these cues were altered by the 3:1 scaling factor and the tiling procedure which added turns and walking distance, as well as disrupted the continuity of the walking process. The individual and combined impact of these factors is unknown. Future research should explore these same issues in an MR space the same size as the actual space, and train without scaling and tiling.

During the design stages of this project, there were two concerns that prompted the use of the spotter within the MR space. One was the chance that a participant might become disoriented or have difficulty maintaining balance as they walked through the MR environment. The other concern was that participants would have difficulty with the tiling concept and need active assistance in moving from one tile to the next. Neither concern was warranted. After having experienced the familiarization trail, participants appeared quite comfortable in the environment, walking through the space without self-protective actions such as searching the area with their hands as they walked. In addition, participants overall were quick to pick up on the tiling procedure, automatically moving to the start of the next tile without specific instruction within the first two to three tile changes.

2. Are spatial abilities test scores (Cube Comparison, and Surface Development from the Manual for Kit of Factor-Referenced Cognitive Tests, (Ekstrom et al., 1976), and the Guilford-Zimmerman Aptitude Survey test of spatial orientation (Guilford, 1948)) correlated with participants' performance on the three performance measurement tasks of time to traverse the learned route, number of errors committed in the timed trial of route traversal, and the ability to be oriented enough to locate the position of the beginning and ending of the route from two separate locations along the route?

In correlation analyses the Surface Development test was found to correlate with the Cube Comparisons test and the Guilford-Zimmerman spatial orientation test, but there was no relationship between the Guilford-Zimmerman and the Cube Comparison test, or between any of these three tests of spatial abilities and the participants' performance on total time to complete the route, or the number of errors made while traversing the route. There was a positive relationship between the time required to complete the route and the number of errors made. The correlation of localization performance scores with the spatial abilities tests were negative, showing that the higher one scored on the standardized tests, the lower their error scores (that is, the better they were at locating the beginning and end of the route at locations from which they could not see either the beginning or the end). There was a positive correlation between the ability to locate the end of the route at the first station from the second station, showing consistency in performance.

3. Is rehearsal of route traversal in the MR environment successful as a training tool as evidenced by the improved performance, measured by decreased total time for each successive trial in the MR environment?

This hypothesis was generally supported by the data, with the time to complete each MR rehearsal decreasing significantly over time. In addition 5 of 6 tiles showed a significant decrease in the amount of time required to traverse that tile between the first and third trials. Time spent in learning the route in this condition varied widely from a maximum first trail of 25 minutes to a minimum first trial of 3.2 minutes, and a maximum third trial of 8.5 minutes to a minimum of 2.2 minutes.

4. Will participation in route rehearsal in the MR environment cause greater symptomology of simulator sickness than in the non-MR environments?

The data gathered using the SSQ and processed by using both the weighted values developed by Kennedy et al. (1993), and the non-weighted values as per Knerr et al. (1998) both indicated that it did not.

The presence of proprioceptive feedback in the MR condition was expected to produce performance scores that were better than paper map rehearsal, and the same as walking through the actual facility. Although that hypothesis was not supported completely, it is very likely that proprioceptive feedback is what led to the lack of simulator sickness among the MR participants. Future research might include a direct comparison of learning route and survey knowledge through this type of MR and through a VE system through which users move by manipulating an

input device such as a mouse or joystick, while physically remaining stationary. Another possible contributing factor is that participants could see a portion of the real world around the bottom and side of the Sony Glasstron. This provided them with a real world visual reference that was consistent with the kinesthetic and vestibular cues they were receiving.

The exploration and confirmation of the training capabilities of MR as implemented using BARS is an important step in the development and application of the system to the U.S. Army training mission. This experiment was designed to examine one potential training area in a small controlled environment, which can be used as the foundation for experimentation with more complex tasks such as wayfinding through an urban environment, and/or in direct comparison to more established VEs to determine strengths and areas for improvement as BARS is considered as an addition to the training mission.

As the power of electronics increases with reductions in cost over time, the utility and affordability of augmented, virtual and MR environments will also increase. The possibility of having small, easy-to-configure mobile units would expand the ability of the Army to enhance its training efforts in the future. To continue this line of research has the potential to expand training opportunities into scenarios not previously thought possible, improve Soldier performance, safety and survivability.

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APPENDIX A

LIST OF ACRONYMS

AR	Augmented Reality
BARS	Battlefield Augmented Reality System
CAD	Computer Aided Design
DV	Dependent Variable
Eds	Editors
EISA	Extended Industry Standard Architecture
GPS	Global Positioning System
GLONASS	Global Navigation Satellite System
HMD	Head Mounted Display
IEEE	Institute of Electrical and Electronics Engineers
LCD	Liquid Crystal Display
MARS	Mobilr Augmented Reality System
MHQ	Motion History Questionniare
MOUT	Military Operations in Urban Terrain
MR	Mixed Reality
NAVAIR	Naval Air Station
NRL	Naval Research Laboratory
PCI	Peripheral Component Interconnect
TVC	Tactical Visual Computer
U.S.	United States
UAV	Unmanned Aerial Vehicle
UCF	University of Central Florida
USMC	United States Marine Corps
VE	Virtual Environment
VESS	Virtual Environment Software Sandbox
VR	Virtual Reality

APPENDIX B

FLOOR PLAN: ROUTE, LANDMARKS AND LOCALIZATION

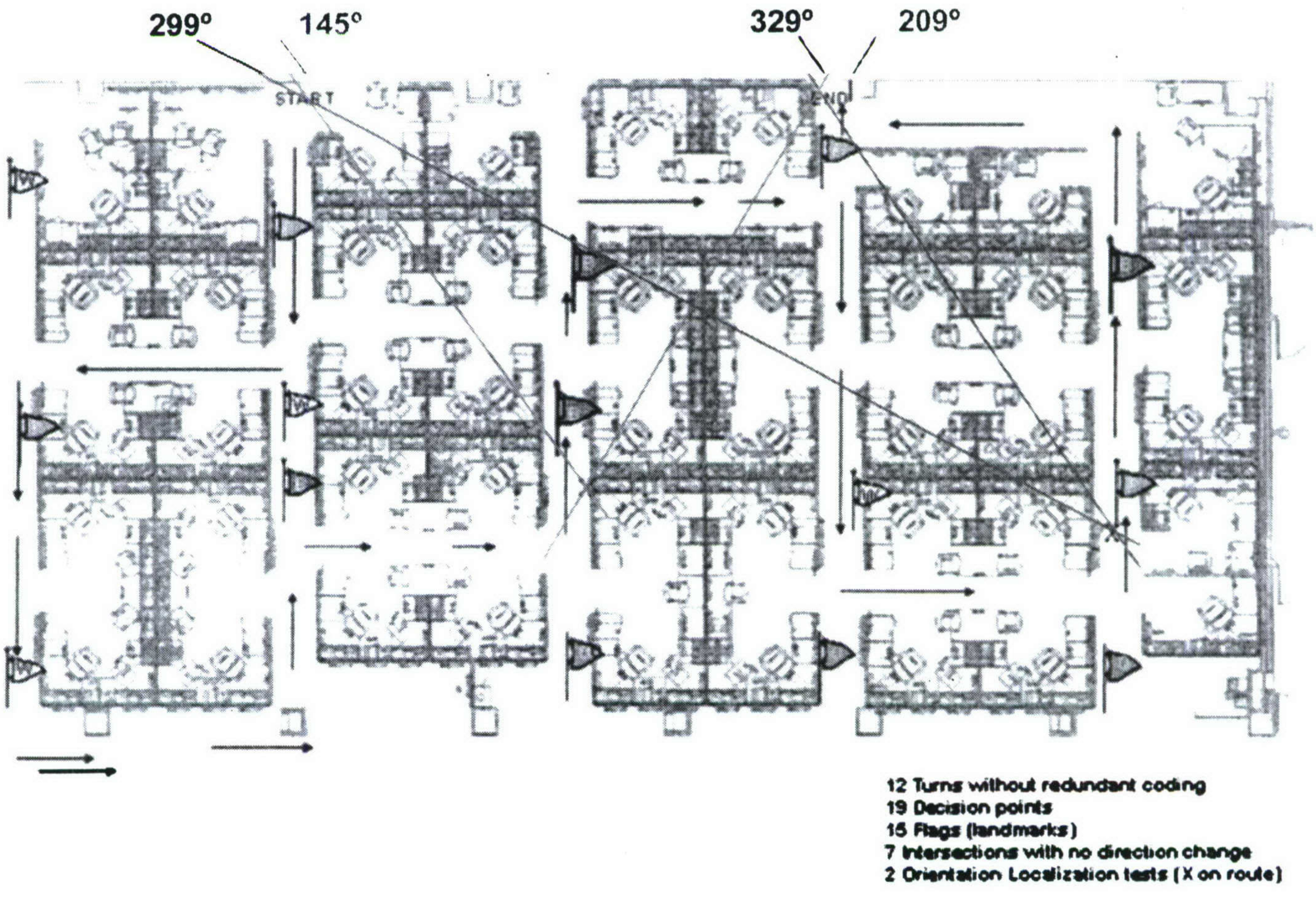


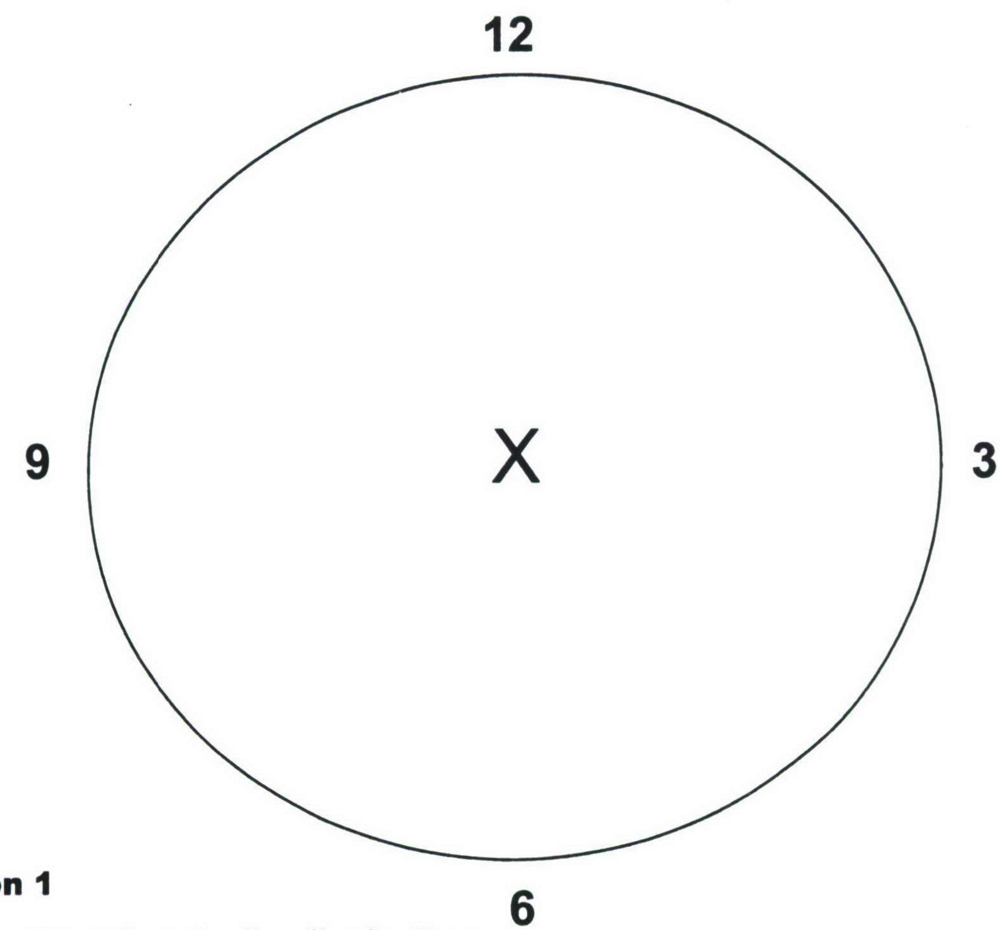
Figure B-1. Diagram of environment showing all information.

APPENDIX C

ORIENTATION LOCALIZATION

Orientation Localization

1. Stand facing the wall where the clipboard is hanging.
2. Imagine yourself standing at the X facing the 12.
3. Use the pen to place an S on the circle where the start of the route is located in reference to the X.
4. Use the pen to place an E on the circle where the end of the route is located in reference to the X.



Location 1

Figure C-1 Orientation Localization Page

APPENDIX D

FLOOR PLAN USED FOR PAPER MAP REHEARSAL

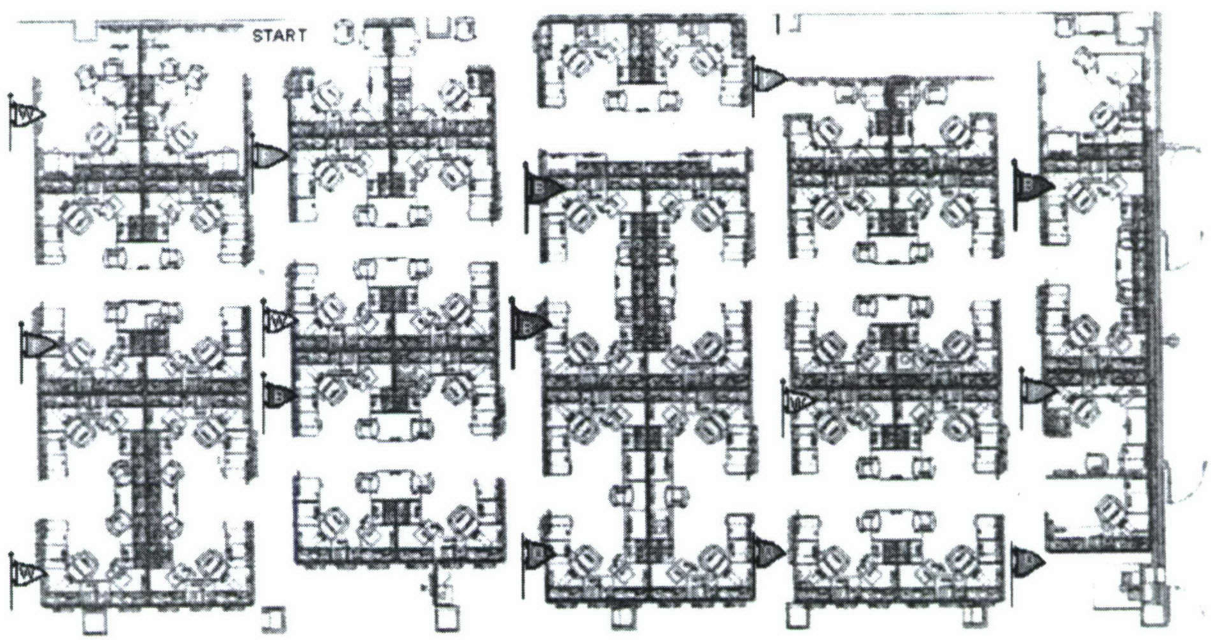


Figure D-1. Floor Plan Used for Paper Map Rehearsal

APPENDIX E

EXPERIMENTER SCRIPTS AND PROCEDURES

Experimental Procedures

(Read this to each **MR** condition participant)

The Experimenter: "Thank you for participating in this experiment. This experiment is part of an Augmented Reality research project sponsored by the Army Research Institute. In general, augmented reality systems add information to the real world using a computer. You will be wearing a vest with a mobile augmented reality system that weighs about 5 pounds. There is a display that is attached to an adjustable headband. The display is designed to adjust to fit over most eyeglasses. The display's position is adjustable and we will help you in adjusting it to a comfortable position. The entire test should take less than three hours.

Your task involves learning to navigate a specific route through an office area. Before putting on the equipment, learning the route and performing the task, you will be asked to fill out an informed consent form, a demographics sheet and take two surveys concerning the way you experience motion. You will then be asked to complete three tests that are used to evaluate your spatial abilities. Do your best on the tests, go in sequence through the questions, and do not go back and redo questions unless you have finished before time is called.

Throughout the training portion of the experiment using the augmented reality equipment, you will be asked to fill out one page surveys concerning your experience in using the system.

If at any time you feel uncomfortable with the situation and want to stop the experiment, please verbalize your intent and we will stop the experiment. Otherwise, we will not respond to questions or comments during your completion of surveys, training in the MR environment, testing the actual office space, or any other tasks.

Do you have any questions so far?"

ACTION: Give the participant the Informed Consent Form and the demographics sheet.

Experimenter: "Please fill out the Informed Consent Form and the demographics sheet".

ACTION: After the participant is done with filling out the consent form and the demographics sheet, administer Motion History Questionnaire.

Experimenter: "Please complete the Motion History Questionnaire."

ACTION: After the participant is done with the motion history questionnaire, administer the Simulator Sickness Questionnaire.

Experimenter: "Please complete the Simulator Sickness Questionnaire."

ACTION: After the participant is done with the Simulator Sickness Questionnaire, administer the Spatial Orientation Test.

Experimenter: "Please complete the following Cube Comparison Test. Read over the instructions on the first page carefully and complete the practice session. You should mark your answers on the test page. Do not turn the page until you are told to do so. Please indicate when you have finished with the first page."

ACTION: When participant has indicated they are prepared to continue…

Experimenter: "You will have 3 minutes to complete one page of cube comparisons. Work as quickly and accurately as possible. Are you ready?"

ACTION: When the participant indicates they're ready, start the stopwatch as you say:

Experimenter: "Go"

ACTION: When 3 minutes have passed say:

Experimenter: "Stop" "You will have 3 minutes to complete one more page of cube comparisons. Work as quickly and accurately as possible. Are you ready?"

ACTION: When the participant indicates they're ready, start the stopwatch as you say:

Experimenter: "Go"
ACTION: When 3 minutes have passed say:
Experimenter: "Stop"
ACTION: After the participant is done with the Cube Comparison test, administer the Visualization test.
Experimenter: "Please complete the following Visualization Test. Read over the instructions on the first page carefully and complete the practice session. You should mark your answers on the test page. Do not turn the page until you are told to do so. Please indicate when you have finished with the first page."
ACTION: When participant has indicated they are prepared to continue…
Experimenter: "You will have 6 minutes to complete 2 pages of the visualization test. Work as quickly and accurately as possible. Are you ready?"
ACTION: When the participant indicates they're ready, start the stopwatch as you say:
Experimenter: "Go"
ACTION: When 6 minutes have passed say:
Experimenter: "Stop. You will have 6 minutes to complete 2 more pages of the visualization test. Work as quickly and accurately as possible. Are you ready?"
ACTION: When the participant indicates they're ready, start the stopwatch as you say:
Experimenter: "Go"
ACTION: When 6 minutes have passed say:
Experimenter: "Stop
ACTION: Remove the visualization test, and present the participant the Spatial Orientation test book. BE SURE TO GIVE THEM A SCANTRON
Experimenter: "Please complete the following exercise. Read over the instruction page carefully and complete the practice session on pages 1, 2, and 3. Please do NOT record your responses to the practice items. When you have finished the practice session and are ready to begin, please let me know. Please do NOT begin working on the remainder of the exercise until instructed to do so".
ACTION: Make sure that you tell them NOT TO WRITE IN THE BOOKLET and record their answers ONLY on the scantron provided! After they let you know that they are done going over the sample items give them a scantron and ask them again to record their answers on the scantron ONLY! Hand them the scantron.
Experimenter: "Please record your answers on the scantron only. Be sure to mark your answer to Test question #8 on the scantron as #1 and continue from there. You have 10 minutes to work on the test. Do not spend too much on one item. If you are finished before the time is called, you may go back and check your work. If you are not sure about the answer to any item, you may guess, but avoid wild guessing. Your score will be the number of correct answers minus a fraction of the number wrong. Are you ready?
ACTION: When the participant indicates they're ready, start the stopwatch as you say:
Experimenter: "Go"
ACTION: At the end of 10 minutes:
Experimenter: "Stop."
ACTION: Collect the scantron and test booklet.
Experimenter: "Please listen carefully to the following instructions. Your task is to study a set of directions, then practice traversing the route that those directions describe. You will have 15 minutes to study those directions. Do you have any questions?"

ACTION: If the participant has no questions, hand them their booklet with the proper Pre-brief statement and directions.
Experimenter: "Please read the Pre-brief statement. When you are finished please let me know."
ACTION: When the participant has read the pre-brief statement, have them don the BARS system and conduct the familiarization task. (See separate instruction.) When the familiarization is complete have the participant return to the testing area, and when they are ready, start the stopwatch as you say:
Experimenter: "You have 15 minutes to study these directions, starting now."
ACTION: When 15 minutes are up, stop the watch, and retrieve the notebook.
Experimenter: "Your practice session will be conducted using an augmented reality system to project a virtual model of the office space through which you will walk using the directions you've studied. Remember each step you take in the model is equal to 3 steps in the real office space. You will have 3 opportunities to walk through the entire route. Remember that when you get to the edge of an area the screen will turn gray or black. When that happens please let us know so we can move you to the next proper position. In addition to the intersections and aisles of office space, you will see the survey flags to use as cues and you will be able to monitor your own movement through the model by the footprints you leave behind you.

If you make a mistake you will be asked to stop, and will have to discover the correct move without instruction and try again. This will be repeated until you make the proper move and have progressed completely through the model.
Please put on the augmented reality system and get comfortable with it".
ACTION: Assist the participant to put on the equipment and adjust the display. When comfortable, move them to the starting point of the first chunk of the route.
Experimenter: "You are about to begin. Do you have any questions?"
ACTION: Perform 3 practice runs through the model. At the end of each practice trial present the POST TEST Symptom Checklist. When finished –
Experimenter: "This completes the practice portion of the experiment. Please remove the augmented reality system."
ACTION: When the equipment has all been removed and stowed give an additional POST TEST Symptom Checklist to complete. Retrieve the form when finished then -
Experimenter: "We will now move to the test environment on the 4th floor of this building."
ACTION: Move to the 4th floor and to the starting point. Be sure the survey flags and clipboards are in place prior to the participant's arrival to the area. Lead the participant to the starting point by the most direct route.
Experimenter: "You will now perform 1 timed trial of the route you practiced previously. At 2 points along the route you will find a clipboard hanging from the wall. You must stop at each, and without removing the clipboard from the wall; imagine yourself standing at the center of the circle on the X, with your nose pointed toward the 12. Without looking around the room, write an S on the circle where you think the start of the route is in relation to your current position, and an E on the circle where you think the end of the route is in relation to your current position. Do you have any questions?"
ACTION: When there are no further questions
Experimenter: "You may begin." START THE STOP WATCH
ACTION: Follow the participant and count the number of errors the make. Be sure they stop and perform the localization task properly. When they reach the end STOP THE STOP WATCH

Experimenter: "This completes the test portion of the experiment. We will now return to the practice area."
ACTION: When you have returned to the training area, be sure to pay them if they are participating for cash payment, then give them a copy of the Debrief Statement along with the Psychology Research Experience Evaluation Form for Participants, and thank them for their participation.

Instructions for Experimenter to Read for BARS Familiarization

First we will help you don the BARS system. Please let the technicians assist you in donning the vest, and the head mounted display. The vest is adjustable using the three straps across the front. Please feel free to request help in adjusting the straps. The head mounted display is also adjustable, but the band must be snug around your head to keep the display from moving while in use.

Please be careful not to catch any of the cables with your hands or pull on them.

Anytime the display presents an empty gray field please tell the technicians.

You will be able to see the floor by looking under the bottom edge of the display.

The image you will see is a model of an office environment made up of cubicles. You should be able to see walls, ceiling, floor, and office furniture along with survey flags, small colored squares hanging from thin sticks that protrude from the walls of the cubicle aisles. If you want to see where you've been, look at the floor through the display directly behind you and you will see your own footprints.

Your movement through this environment will be 3 times faster than in the real world. **Each step you take in the model is worth 3 steps in the real world.**

The model is broken into sections. When you reach the end of a section the display will turn a solid gray and you should stop walking. You will then be directed to move to one of the yellow spots on the floor identified with a black letter.

When the display appears and you can see it clearly, look straight ahead, take 2 steps straight forward and stop. Turn your head slowly to the left. (Pause) Now turn slowly to the right. (Pause). Return slowly to looking forward.

Now, turn your head quickly to the left, quickly to the right, and return quickly to center. Note the difference in the appearance of the model depending on the speed with which you move your head. Look at the floor through the display and turn around to see your own footprints directly behind you.

Please take a few minutes to walk through this space. Be careful to stay in the aisles because there is nothing to stop you from walking through a wall, which is likely to be disorienting. Be sure to turn left and right to walk into cubicles and see the furniture in them. Note the presence of survey flags.

When you have reached the edge of the section the display will look gray. Please let the technician know when that happens so you can be directed to your next starting point.

When you have been repositioned and the office model appears in the display you will be in the same position as you were before the display turned gray. Please use this section to explore the area, as you like. When you feel familiar with moving through the model please let us know so we may continue with the next part of the experiment.

Do you have any questions?

MR Rehearsal Instructions

You will be positioned at the starting point of the route, with your back to the windows.
Please walk the route that you have learned.
If you make an error, you will be told to stop, and must determine how to correct your movement without input from the technician.
When the display shows a solid gray please stop and allow the technician to re-position you at the starting point of the next tile.
You will perform 3 practice trials of the entire route through the model.
Do you have any questions?

Walking Rehearsal Instructions

(Read this to each **WALKING** condition participant)

The Experimenter: "Thank you for participating in this experiment. This experiment is part of an Augmented Reality research project sponsored by the Army Research Institute. In general, augmented reality systems add information to the real world using a computer. The entire test should take less than two hours.

Your task involves learning to navigate a specific route through an office area. Before learning the route and performing the task, you will be asked to fill out an informed consent form, a demographics sheet and take two surveys concerning the way you experience motion. You will then be asked to complete three tests that are used to evaluate your spatial abilities. Do your best on the tests, go in sequence through the questions, and do not go back and redo questions unless you have finished before time is called.

If at any time you feel uncomfortable with the situation and want to stop the experiment, please verbalize your intent and we will stop the experiment. Otherwise, we will not respond to questions or comments during your completion of surveys, training, or testing.

Do you have any questions so far?"

ACTION: Give the participant the Informed Consent Form and the demographics sheet.

Experimenter: "Please fill out the Informed Consent Form and the demographics sheet".

ACTION: After the participant is done with filling out the consent form and the demographics sheet, administer Motion History Questionnaire.

Experimenter: "Please complete the Motion History Questionnaire."

ACTION: After the participant is done with the motion history questionnaire, administer the Simulator Sickness Questionnaire.

Experimenter: "Please complete the Simulator Sickness Questionnaire."

ACTION: After the participant is done with the Simulator Sickness Questionnaire, administer the Spatial Orientation Test.

Experimenter: "Please complete the following Cube Comparison Test. Read over the instructions on the first page carefully and complete the practice session. You should mark your answers on the test page. Do not turn the page until you are told to do so. Please indicate when you have finished with the first page."

ACTION: When participant has indicated they are prepared to continue...

Experimenter: "You will have 3 minutes to complete one page of cube comparisons. Work as quickly and accurately as possible. Are you ready?"

ACTION: When the participant indicates they're ready, start the stopwatch as you say:

Experimenter: "Go"

ACTION: When 3 minutes have passed say:

Experimenter: "Stop" "You will have 3 minutes to complete one more page of cube comparisons. Work as quickly and accurately as possible. Are you ready?"

ACTION: When the participant indicates they're ready, start the stopwatch as you say:

Experimenter: "Go"

ACTION: When 3 minutes have passed say:

Experimenter: "Stop"

ACTION: After the participant is done with the Cube Comparison test, administer the Visualization test.

Experimenter: "Please complete the following Visualization Test. Read over the instructions on the first page carefully and complete the practice session. You should mark your answers on the test page. Do not turn the page until you are told to do so. Please indicate when you have finished with the first page."
ACTION: When participant has indicated they are prepared to continue…
Experimenter: "You will have 6 minutes to complete 2 pages of the visualization test. Work as quickly and accurately as possible. Are you ready?"
ACTION: When the participant indicates they're ready, start the stopwatch as you say:
Experimenter: "Go"
ACTION: When 6 minutes have passed say:
Experimenter: "Stop. You will have 6 minutes to complete 2 more pages of the visualization test. Work as quickly and accurately as possible. Are you ready?"
ACTION: When the participant indicates they're ready, start the stopwatch as you say:
Experimenter: "Go"
ACTION: When 6 minutes have passed say:
Experimenter: "Stop
ACTION: Remove the visualization test, and present the participant the Spatial Orientation test book. BE SURE TO GIVE THEM A SCANTRON
Experimenter: "Please complete the following exercise. Read over the instruction page carefully and complete the practice session on pages 1, 2, and 3. Please do NOT record your responses to the practice items. When you have finished the practice session and are ready to begin, please let me know. Please do NOT begin working on the remainder of the exercise until instructed to do so".
ACTION: Make sure that you tell them NOT TO WRITE IN THE BOOKLET and record their answers ONLY on the scantron provided! After they let you know that they are done going over the sample items give them a scantron and ask them again to record their answers on the scantron ONLY! Hand them the scantron.
Experimenter: "Please record your answers on the scantron only. Be sure to mark your answer to Test question #8 on the scantron as #1 and continue from there. You have 10 minutes to work on the test. Do not spend too much on one item. If you are finished before the time is called, you may go back and check your work. If you are not sure about the answer to any item, you may guess, but avoid wild guessing. Your score will be the number of correct answers minus a fraction of the number wrong. Are you ready?
ACTION: When the participant indicates they're ready, start the stopwatch as you say:
Experimenter: "Go"
ACTION: At the end of 10 minutes:
Experimenter: "Stop."
ACTION: Collect the scantron and test booklet.
Experimenter: "Please listen carefully to the following instructions. Your task is to study a set of directions, then practice traversing the route that those directions describe. You will have 15 minutes to study those directions. Do you have any questions?"
ACTION: If the participant has no questions, hand them their booklet with the proper Pre-brief statement and directions.
Experimenter: "Please read the Pre-brief statement. When you are finished please let me know."

ACTION: When the participant has read the pre-brief statement, and when they are ready, start the stopwatch as you say:
Experimenter: "You have 15 minutes to study these directions, starting now."
ACTION: When 15 minutes are up, stop the watch, and retrieve the notebook.
Experimenter: "Your practice session will be conducted by walking through the actual office space. You will have 3 opportunities to walk through the entire route. In addition to the intersections and aisles of office space, you will see the survey flags to use as cues.

If you make a mistake you will be asked to stop, and will have to discover the correct move without instruction and try again. This will be repeated until you make the proper move and progressed completely through the route. We will now move to the test environment on the 4th floor of this building."
ACTION: Move to the 4th floor and to the starting point. Be sure the survey flags and clipboards are in place prior to the participant's arrival to the area. Lead the participant to the starting point by the most direct route.
Experimenter: "You will now perform 3 practice trials of the route you have studied as previously described."
ACTION: Perform 3 practice runs through the space. At the end of the practice session present the POST TEST Symptom Checklist. When finished –
Experimenter: "This completes the practice portion of the experiment.
You will now perform 1 timed trial of the route you practiced previously. At 2 points along the route you will find a clipboard hanging from the wall. You must stop at each, and without removing the clipboard from the wall; imagine yourself standing at the center of the circle on the X, with your nose pointed toward the 12. Without looking around the room, write an S on the circle where you think the start of the route is in relation to your current position, and an E on the circle where you think the end of the route is in relation to your current position. Do you have any questions?"
ACTION: When there are no further questions
Experimenter: "You may begin." START THE STOP WATCH
ACTION: Follow the participant and count the number of errors the make. Be sure they stop and perform the localization task properly. When they reach the end STOP THE STOP WATCH
Experimenter: "This completes the test portion of the experiment. We will now return to the practice area."
ACTION: When you have returned to the training area, be sure to pay them if they are participating for cash payment, then give them a copy of the Debrief Statement along with the Psychology Research Experience Evaluation Form for Participants, and thank them for their participation.

Route Drawing Rehearsal Instructions

(Read this to each **MAP** condition participant)

The Experimenter: "Thank you for participating in this experiment. This experiment is part of an Augmented Reality research project sponsored by the Army Research Institute. In general, augmented reality systems add information to the real world using a computer. The entire test should take less than two hours.

Your task involves learning to navigate a specific route through an office area. Before learning the route and performing the task, you will be asked to fill out an informed consent form, a demographics sheet and take two surveys concerning the way you experience motion. You will then be asked to complete three tests that are used to evaluate your spatial abilities. Do your best on the tests, go in sequence through the questions, and do not go back and redo questions unless you have finished before time is called.

If at any time you feel uncomfortable with the situation and want to stop the experiment, please verbalize your intent and we will stop the experiment. Otherwise, we will not respond to questions or comments during your completion of surveys, training, or testing.

Do you have any questions so far?"

ACTION: Give the participant the Informed Consent Form and the demographics sheet.

Experimenter: "Please fill out the Informed Consent Form and the demographics sheet".

ACTION: After the participant is done with filling out the consent form and the demographics sheet, administer Motion History Questionnaire.

Experimenter: "Please complete the Motion History Questionnaire."

ACTION: After the participant is done with the motion history questionnaire, administer the Simulator Sickness Questionnaire.

Experimenter: "Please complete the Simulator Sickness Questionnaire."

ACTION: After the participant is done with the Simulator Sickness Questionnaire, administer the Spatial Orientation Test.

Experimenter: "Please complete the following Cube Comparison Test. Read over the instructions on the first page carefully and complete the practice session. You should mark your answers on the test page. Do not turn the page until you are told to do so. Please indicate when you have finished with the first page."

ACTION: When participant has indicated they are prepared to continue...

Experimenter: "You will have 3 minutes to complete one page of cube comparisons. Work as quickly and accurately as possible. Are you ready?"

ACTION: When the participant indicates they're ready, start the stopwatch as you say:

Experimenter: "Go"

ACTION: When 3 minutes have passed say:

Experimenter: "Stop" "You will have 3 minutes to complete one more page of cube comparisons. Work as quickly and accurately as possible. Are you ready?"

ACTION: When the participant indicates they're ready, start the stopwatch as you say:

Experimenter: "Go"

ACTION: When 3 minutes have passed say:

Experimenter: "Stop"

ACTION: After the participant is done with the Cube Comparison test, administer the Visualization test.

Experimenter: "Please complete the following Visualization Test. Read over the instructions on the first page carefully and complete the practice session. You should mark your answers on the test page. Do not turn the page until you are told to do so. Please indicate when you have finished with the first page."
ACTION: When participant has indicated they are prepared to continue…
Experimenter: "You will have 6 minutes to complete 2 pages of the visualization test. Work as quickly and accurately as possible. Are you ready?"
ACTION: When the participant indicates they're ready, start the stopwatch as you say:
Experimenter: "Go"
ACTION: When 6 minutes have passed say:
Experimenter: "Stop. You will have 6 minutes to complete 2 more pages of the visualization test. Work as quickly and accurately as possible. Are you ready?"
ACTION: When the participant indicates they're ready, start the stopwatch as you say:
Experimenter: "Go"
ACTION: When 6 minutes have passed say:
Experimenter: "Stop
ACTION: Remove the visualization test, and present the participant the Spatial Orientation test book. BE SURE TO GIVE THEM A SCANTRON
Experimenter: "Please complete the following exercise. Read over the instruction page carefully and complete the practice session on pages 1, 2, and 3. Please do NOT record your responses to the practice items. When you have finished the practice session and are ready to begin, please let me know. Please do NOT begin working on the remainder of the exercise until instructed to do so".
ACTION: Make sure that you tell them NOT TO WRITE IN THE BOOKLET and record their answers ONLY on the scantron provided! After they let you know that they are done going over the sample items give them a scantron and ask them again to record their answers on the scantron ONLY! Hand them the scantron.
Experimenter: "Please record your answers on the scantron only. Be sure to mark your answer to Test question #8 on the scantron as #1 and continue from there. You have 10 minutes to work on the test. Do not spend too much on one item. If you are finished before the time is called, you may go back and check your work. If you are not sure about the answer to any item, you may guess, but avoid wild guessing. Your score will be the number of correct answers minus a fraction of the number wrong. Are you ready?
ACTION: When the participant indicates they're ready, start the stopwatch as you say:
Experimenter: "Go"
ACTION: At the end of 10 minutes:
Experimenter: "Stop."
ACTION: Collect the scantron and test booklet.
Experimenter: "Please listen carefully to the following instructions. Your task is to study a set of directions, then practice the route that those directions describe. You will have 15 minutes to study those directions. Do you have any questions?"
ACTION: If the participant has no questions, hand them their booklet with the proper Pre-brief statement and directions.
Experimenter: "Please read the Pre-brief statement. When you are finished please let me know."

ACTION: When the participant has read the pre-brief statement, and when they are ready, start the stopwatch as you say:
Experimenter: "You have 15 minutes to study these directions, starting now."
ACTION: When 15 minutes are up, stop the watch, and retrieve the notebook.
Experimenter: "Your practice session will be conducted by drawing the route on a floor plan of the actual office space. You will have 3 opportunities to draw the entire route. In addition to the intersections and aisles of office space, you will see the survey flags to use as cues.

If you make a mistake you will be asked to stop, and will have to discover the correct move without instruction and try again. This will be repeated until you make the proper move and have progressed completely through the route."
ACTION: Perform 3 practice drawings through the space. At the end of the practice session present the POST TEST Symptom Checklist. When finished –
Experimenter: "This completes the practice portion of the experiment. We will now move to the test area on the 4th floor of this building.
ACTION: Move to the 4th floor and to the starting point. Be sure the survey flags and clipboards are in place prior to the participant's arrival to the area. Lead the participant to the starting point by the most direct route.
Experimenter: "You will now perform 1 timed trial of the route you practiced previously. At 2 points along the route you will find a clipboard hanging from the wall. You must stop at each, and without removing the clipboard from the wall; imagine yourself standing at the center of the circle on the X, with your nose pointed toward the 12. Without looking around the room, write an S on the circle where you think the start of the route is in relation to your current position, and an E on the circle where you think the end of the route is in relation to your current position. Do you have any questions?"
ACTION: When there are no further questions
Experimenter: "You may begin." START THE STOP WATCH
ACTION: Follow the participant and count the number of errors the make. Be sure they stop and perform the localization task properly. When they reach the end STOP THE STOP WATCH
Experimenter: "This completes the test portion of the experiment. We will now return to the practice area."
ACTION: When you have returned to the training area, be sure to pay them if they are participating for cash payment, then give them a copy of the Debrief Statement along with the Psychology Research Experience Evaluation Form for Participants, and thank them for their participation.

APPENDIX F

DEMOGRAPHICS QUESTIONNAIRE

Demographics Questionnaire

Participant number: __________ **Date: _________**

Male _____ **Female _____** **Age: _____**

Year in School: ______________________ **Major: ________________________**

Is your vision corrected to 20/20? **YES** **NO**

Do you have any color vision deficiency? **YES** **NO**

If yes, please describe:

How many hours a week do you spend using a computer? _____

How many hours a week do you spend playing video games? _____

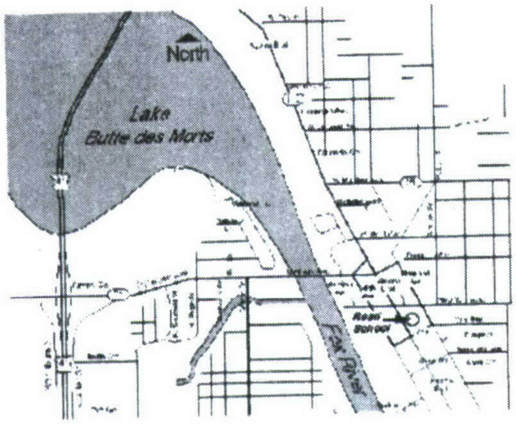
On a scale of 1 to 10, with one meaning you are never misoriented and 10 meaning you always have trouble finding your way around, how would you rate your sense of direction?

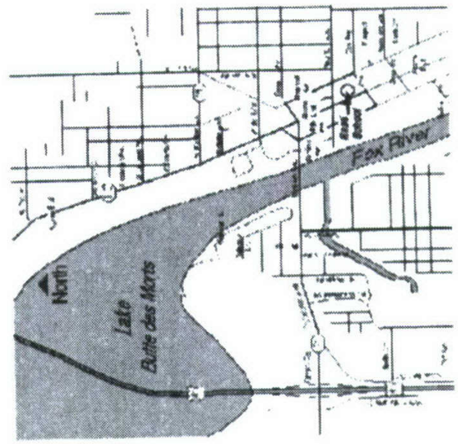
_____

How often do you use a map?

Never _____ Once a week _____ Once a month _____ Once a year _____

When you use a map do you always orient the map with north up, or do you rotate the map based on your direction of travel?


North
Lake
Butte des Morts
Fox River

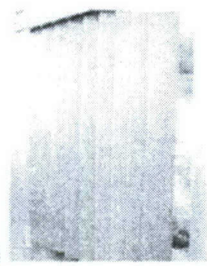

Fox River
North
Lake
Butte des Morts

APPENDIX G

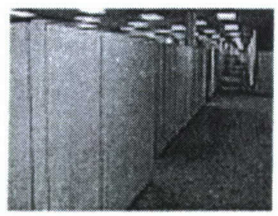
ROUTE DIRECTIONS FOR MEMORIZATION

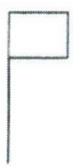
Route Directions

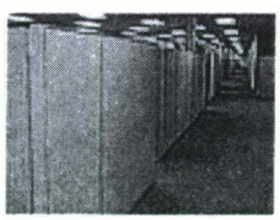
Please study the following directions to walk from one point to another along this specific route.

Stand with your back to the windows 

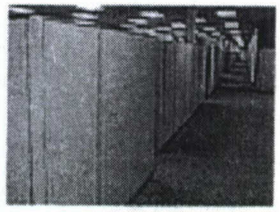
Walk forward past the pink flag 

Turn right and walk to the next intersection 

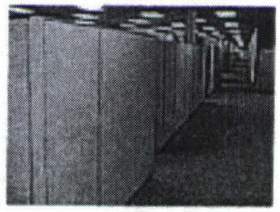
Turn left and walk past the white flag 

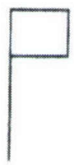
Turn left and walk to the intersection 

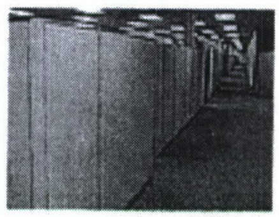
Turn left and walk toward the blue flag 

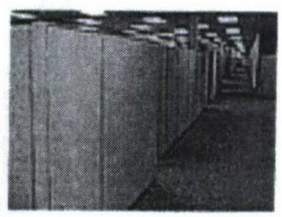
Turn right and walk to the next intersection 

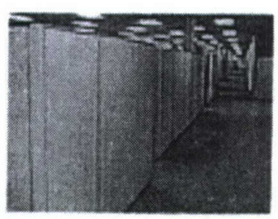
Turn left and walk past 2 blue flags 

Turn right and walk to the next intersection 

Turn right and walk past the white flag 

Turn left and walk to the next intersection 

Turn left and walk past the blue flag to the next intersection 

Turn left and walk to the next intersection 

Turn right and end facing the window